AFIT/GOR/ENS/94M-20



# THE EFFECTIVE USE OF ANIMATION IN SIMULATION MODEL VALIDATION

THESIS

Christopher L. Swider
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DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY



Wright-Patterson Air Force Base, Ohio

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# THE EFFECTIVE USE OF ANIMATION IN SIMULATION MODEL VALIDATION

THESIS

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Major, USAF


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Christopher L. Swider

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## Abstract

This study examined two animation displays (moving icons, bar graphs) at two presentation speeds to determine how each of these factors affected the animation's ability to communicate violations of model assumptions. Subjects viewed animation displays individually and *in combination* at each of the presentation speeds. Eight problem scenarios were presented to evaluate each animation's ability to communicate violations of different assumptions. Each animation's communication ability was measured both subjectively and objectively. Subjective measures in the form of pairwise comparisons were used to calculate normalized preference ratings for each animation. Objective measures included problem identification accuracy and problem response time. Subjective results indicated that moving icons and the slower presentation speed were the preferred factor levels. However, the combined display of bar graphs and moving icons was preferred most at the slower presentation speed. Objective results indicated that moving icons and the slower presentation speed were factor levels which significantly improved identification accuracy and response times for most problem scenarios. Although subjects preferred the combined display at the slower presentation speed, they performed equally well with either moving icon animation.

# THE EFFECTIVE USE OF ANIMATION IN SIMULATION MODEL VALIDATION

## I. Introduction

### Background

Computer simulation has become increasingly popular and practical with the proliferation of computing resources in recent years. In the Department of Defense, computer simulations are used to model war, weapon systems effectiveness, logistics problems, and personnel issues among others. With diminishing resources, these models are increasingly vital analysis tools. Their early use often indicates potential problems in a system or strategy before it has been fielded or implemented. The value of these analytical tools depends upon a valid model and a sound computer implementation of this model.

A model is a description of a system of interrelated elements acted upon by outside forces. A complex system has many elements and detailed relationships among them. Models of complex systems are abstractions which portray the most significant system elements and their key interrelationships. This abstract representation reduces the complexity of the system to a manageable level yet retains important characteristics of the modeled system. An abstract model's ability to faithfully represent particular characteristics of a more complex system determines its validity as a model of that system.

A computer simulation model is a mathematical-logical system model functioning within the framework of a computer operating system. The validity of computer simulation models depends on the validity of the original abstraction and the validity of the computer implementation. Model validity is not universal but confined to the system qualities under investigation. Validation of a computer simulation model requires " a

substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model" (Schlesinger and others, 1979:103). Validation of a simulation model is essential to sound analysis of the system under study and is therefore the subject of considerable study.

There are a wide range of validation techniques for simulation models. Sargent lists 17 techniques including an analysis of underlying model assumptions, expert opinions, comparisons to other valid models, tests on historical data and sensitivity analysis (Sargent, 1992:106-107). Verification is also important to insure error-free computer programming and implementation of the conceptual model. Both validation and verification are required for sound analysis, but validation is more difficult to accomplish.

Validation is more difficult because it cannot be established with certainty. The combination of subjective and objective techniques in a validation effort only increase user confidence in the likelihood that the model is valid over its intended range of application. There is no recognized technique or group of techniques for every simulation validation. Carson recommends a three-step approach to validation:

1) Develop a model with high face validity
2) Validate model assumptions
3) Validate model output

For models where entities move through space, Carson recommends animation as a useful tool for establishing face validity and validating model assumptions (Carson, 1989:555).

Computer animation is one of the most recent techniques to gain acceptance in model validation. Its growing acceptance is related to an increase in graphics software capabilities and the proliferation of quality graphics displays. As the cost of these tools has dropped, use of animation has soared. One reason for the success of animation in validation is its influence on decision-makers. Law and Kelton feel that animation's

expanding use is primarily due to its ability to increase model credibility and thereby influence decision-makers (Law and Kelton, 1991:241). The manner in which such graphics enhance model credibility is not always clear, but there is little doubt that a skillful animation provides credible evidence to support model validation.

## Problem Statement

Animation has two key uses in simulation validation. One suggested use is in establishing the face validity of a simulation model (Carpenter, 1991:3; Carson, 1989:555). Sargent defines face validity as "...asking people knowledgeable about the system whether the model and/or its behavior is reasonable." Face validity is used to determine if a model's input-output relationships are reasonable and if the underlying logic of the conceptual model is correct (Sargent, 1992:106). Carson also feels that animation is useful in testing whether a model is faithful to its underlying assumptions (Carson, 1989:555). In both uses, animation is useful when it effectively communicates the behavior of the simulation model.

Animation is useful because it graphically portrays the model's operational behavior over time. Unfortunately, there are few available guidelines on how to effectively animate model output. This research will investigate the effectiveness of animation in portraying model behavior. The results of this investigation will provide guidance for the selection of animation techniques that are most effective in communicating model behavior. The use of more effective animation techniques will make animation a better validation tool.

## Research Objective

Animation is a new tool in simulation model validation. The acid tests for the utility of any new analytical tool are whether it is accepted by those who use it, easily understood, and effective in solving problems. The growing use of animation attests to

the tool's increased acceptance and understandability among simulation users. This research will test six different animations to determine which one(s) are most effective in communicating model problems. The problems which each animation will portray are violations of model assumptions. The aspects of animation to be evaluated are moving icons, bar graphs, and viewing speed. Animation presentations with moving icons and bar graphs will be evaluated individually and in combination at two animation speeds.

## Assumptions and Scope

**Simulation Model.** Examining the effectiveness of the selected animations requires an appropriate simulation model. The model should be simple enough to highlight the differences in the selected animations, but complex enough to be representative of a useful simulation application. For this analysis, the simulation model was taken from the text *Introduction to Simulation and SLAM II* (Pritzker, 1986:203-208). The model depicts the control of two-way traffic along a one-lane road using traffic lights placed at both ends of the one-lane road segment. The timing of these traffic lights allows longer access in the more heavily traveled direction and also allows time for the lane to clear before the direction of traffic flow is reversed. This Single-Lane Traffic Analysis model will be referred to as the Traffic model.

**Animation Software.** The Traffic model will be animated using Proof Animation, a PC-based, "post-processing" animation software. For post-processing animation software, the animation is based on a trace file generated from a simulation run. The results of the simulation are pre-recorded and cannot be changed while the animation is running. This is different from concurrent animation software where some changes made during the simulation run can be observed immediately in the animated output (Law and Kelton, 1991:241). The advantages of using post-processing animation software

are portability and flexibility of output. The animation output can be rewound or fast-forwarded and the speed of the presentation can be changed (Henriksen and Earle, 1992:368).

## Research Approach

Subjects will view each animation in the experiment to determine which one most effectively communicates the operation of the model. Effectiveness will be based on the subjects' ability to recognize when model assumptions are being violated. Both the time and the accuracy of each subject's responses will be recorded.

After viewing the animations, subjects will also identify their preferences for each animation type that they have viewed. Pairwise comparisons between each animated presentation will provide subjective information to rate each animation's ability to communicate model behavior. This pairwise comparison is known as the Analytic Hierarchy Process and is discussed in the next chapter.

## Overview

Chapter 2 reviews the current literature on simulation model validation, animation, display design , and the Analytic Hiearchy Process. Chapter 3 describes the research approach, including the Traffic Model, the animations, the experimental design, and the analysis methods. Chapter 4 details the statistical analysis and significant results of the experiment. Chapter 5 discusses the practical significance of the statistical results and the final chapter presents conclusions and recommendations.

There are three appendices. Appendix A provides an example of the forms used to conduct the experiment. Appendix B contains the SAS programs and the experimental data. Appendix C provides listings of the SLAM and FORTRAN code used to create the animations for this research.

# II. Literature Review

## Scope of Presentation

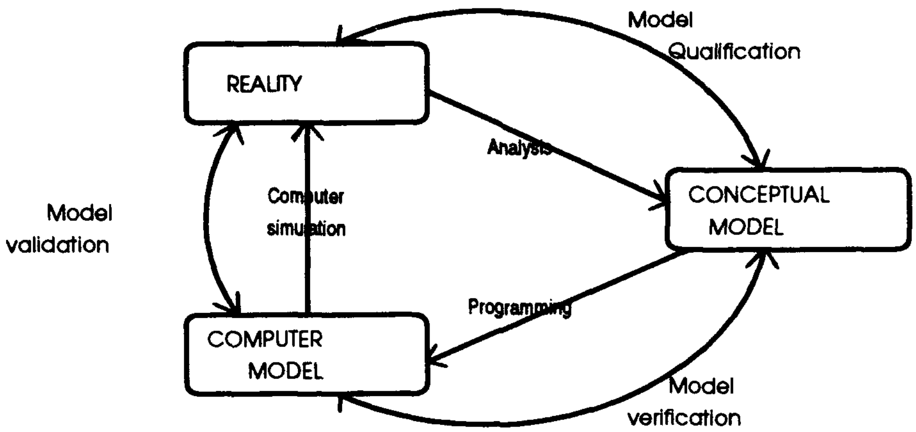
This review includes four topic areas and a concluding summary. The discussion begins with simulation model validation. Model validation is viewed as one element in a three step credibility process. Common validation approaches are discussed with emphasis on the applicability of animation in each approach. Next, the review examines animation's ability to display model behavior from the perspectives of animation vendors, simulation consultants, and academics. Then, research in display design is examined with a look at current theory and the empirical effectiveness of selected techniques. The final topic is a discussion of the Analytic Hierarchy Process as an analytical tool for making subjective evaluations among alternatives. The discussion concludes with a brief summary of the reviewed material.

## Discussion

**Simulation Model Validation.** Over the past 30 years, computer simulation model validation has been the subject of considerable interest. Balci and Sargent list more than 300 articles about validation and model credibility assessments written before 1983 (Balci and Sargent, 1984:15-27). In the past 10 years, interest in validation has grown rapidly with the dynamic growth in simulation. This discussion has generated many opinions about the most appropriate validation approaches for various simulation models. While approaches may differ, the basic procedure for establishing the validity and credibility of a simulation model is largely the same.

**Model Credibility Framework.** A computer simulation model must be valid to be credible for a particular application. In 1979, the Society for Computer Simulation's

Technical Committee on Model Credibility established a standard framework for such credibility. Figure 2.1 shows the relationship of elements in this framework.




The basic elements of a simulation model and their interrelationships (Schlesinger and others, 1979:103)

**Figure 2.1 Simulation Model Credibility Framework**

The basic elements of this framework that relate to model validation are defined as follows (Schlesinger and others, 1979:103-104):

- <u>REALITY</u>: An entity, situation, or system which has been selected for analysis.
- <u>CONCEPTUAL MODEL</u>: Verbal description, equations, governing relationships, or "natural laws" that purport to describe REALITY.
- <u>COMPUTER MODEL</u>: An operational computer program which implements a CONCEPTUAL MODEL.
- <u>DOMAIN OF APPLICABILITY</u>: Prescribed conditions for which the COMPUTER MODEL has been tested, compared against REALITY... and judged suitable for use.

- RANGE OF ACCURACY: Demonstrated agreement between the COMPUTER MODEL and REALITY within a stipulated DOMAIN OF APPLICABILITY.

- MODEL VALIDATION: Substantiation that a COMPUTER MODEL within its DOMAIN OF APPLICABILITY possesses a satisfactory RANGE OF ACCURACY consistent with the intended application of the model.

A valid model depends on *analysis* to create a qualified **conceptual model** and *programming* to code a verifiable computer program of the **conceptual model**. The resulting **computer model** is deemed valid if the output of *computer simulation* experiments is representative of the real system. The essence of a valid *computer simulation* is the ability to mimic **reality** well enough to make sound decisions about real systems based on data gathered from computer experiments (Schlesinger, 1979:103-104).

**Common Model Validation Approaches.** Sargent uses a three part validation approach. He validates the conceptual model, the input data, and the *operational validity of the output.* According to Sargent, most validation testing supports the operational validity of model output. Operational validity encompasses other validation and verification tasks because deficiencies in the input data , computer model, or conceptual model are often found during operational validation. An operationally valid model is one with output that is accurate for a particular purpose under specific conditions. A different purpose or set of conditions requires a new validation effort. Since many operational conditions exist, it is usually impractical to validate a model over all potential conditions (Sargent, 1992: 109).

Sargent divides validation techniques into subjective and objective categories. Objective techniques use statistical evidence from confidence intervals or hypothesis tests to validate a model. Subjective techniques are methods without statistical analysis. Technique selection is arbitrary since no formal procedure exists to match specific techniques with particular model validations. Sargent lists 17 common validation

techniques. Animation (operational graphics) is defined as a technique which employs "...a graphical display of the operational behavior of the model over time" (Sargent, 1992:106).

Balci places model validation within a hierarchy of 13 credibility assessment stages required to evaluate the acceptability of simulation results (Balci, 1989:66). Like Sargent, he classifies validation techniques into statistical and subjective categories. The applicability of each technique depends on the availability of operational data from the modeled system. If system data is available, statistical comparisons with model output data are most appropriate. Without system data, validations must rely on subjective techniques. Although Balci provides examples of 18 statistical and 13 subjective validation techniques, he does not include animation among them (Balci, 1989:68).

Law and Kelton augment a three-step validation approach originally developed by Naylor and Finger (1967:92-101). Their first step is to develop a model with high face validity. Face validity is the confidence that knowledgeable users have about the model's ability to reasonably represent the actual system. Law and Kelton feel this step is best accomplished through conversations with system experts, observation of the system, or comparison to other models or theory. The second validation step requires empirical tests of model assumptions. Examples of these tests include statistical tests to determine input data distributions and sensitivity analysis of model output. The final validation step compares output data from the simulation to data from the modeled system.

Animation is a key technique in Carson's application of the standard three-step model validation. In the first step, Carson uses animation to help establish face validity because it allows users to "*see* model assumptions in action rather than depending on the modeler's assurance and long-run statistical output..." (Carson, 1989:555). Carson also advocates animation in the second validation step where model assumptions are tested. He feels that observing the model in action reveals many key assumptions and helps

establish their accuracy. The final validation step requires a data comparison between system and model output data. Animation is not useful in this final step because statistical analysis is required (Carson, 1989:556-557).

As the previous discussion shows, there are a variety of opinions on validation of simulation models. Techniques vary depending on how the validation is accomplished. Animation does not receive the same emphasis in all validation approaches. Some simulation practitioners feel animation is valuable throughout the entire life cycle of model development. Others view animation's role in more limited terms. A look at these different views lends insight into the potential benefits and limitations of this validation tool.

## Uses for Animation

**Software Vendor Perspective.** The enthusiasm for animation is greatest among those who sell animation software. These vendors argue for animation throughout the design process including verification, validation, and presentation of results (Henriksen and Earle, 1992:366-370; Haigh, 1992:400-404; Hollocks, 1984:323-328; Kalasky and Davis, 1991:122-127; Standridge, 1986:121-143). One shared contention is that animation is required to identify bottlenecks since these dynamic interactions are not visible in standard simulation output (Kalasky and Davis, 1991:122). Haigh agrees, citing "understanding of the modeled system" as the most important benefit gained from animating the model (Haigh, 1992:402). Kalasky and Davis feel model assumptions are clearly represented and more easily seen with animated output. (See also Standridge, 1986:121 and Hollocks, 1984:327). Despite such high regard for animation in general, some vendors concede that animation cannot replace a standard statistical output analysis ( Hollocks, 1984:326; Kalasky and Davis, 1991:123).

**Simulation Consultant Perspective.** Another group of animation advocates are simulation consultants who use animation in their modeling efforts. These practitioners value animation in model development, analysis, and most importantly in the presentation of the model to their customers (Cyr, 1992:1000-1003; Carson and Atala, 1990:798-8011; Johnson and Poorte, 1988:30-36; Zhao and Pirasteh, 1991:402-410).

Johnson and Poorte advocate a hierarchical approach to animation. Their first level of animation is a basic one which only the modeler can recognize. This basic level serves primarily as a debugging and verification tool early in the model development process. The second level is more recognizable, particularly to those who are somewhat familiar with the modeled system. This level is useful for debugging, but can also serve the system expert who is validating the model. The final level of animation has presentation quality graphics. This level of detail is appropriate for communicating model behavior to unfamiliar viewers in managerial presentations, teaching, and sales (Johnson and Poorte, 1988:32).

Cyr is one of the more enthusiastic proponents for animation. His experience with a Monte Carlo simulation suggests several potential benefits of animation including:

- a greater capability to explain the simulation concept to upper-level managers and others who are not expert in mathematics and statistics
- better communication and client understanding of the modeled system
- the ability to demonstrate actual/potential problems with the system being modeled which are more difficult to understand from raw data
- the ability to demonstrate problems with the model itself that would otherwise be difficult to detect

Although the animation effort requires extra time and effort, Cyr feels the advantages clearly justify the extra effort (Cyr, 1991:1000-1002).

One obvious use for animation is to display entities moving through a system. Carson feels this depiction is most significant in the validation of models with interacting entities (Carson, 1989:555). He recently used this capability to enhance the validity of a subway transportation model ( Carson and Atala, 1990:798-801). Zhao and Pirasteh also value animation for models with moving, interactive entities. They feel that their animation of a material handling system gave systems engineers operational experience with the system before it was built and provided information that led to a better design of the actual system . They see benefits in using animation throughout the entire life cycle of the system's development ( Zhao and Pirasteh, 1992:409).

Consultants may appreciate animation for different reasons, but they all share an appreciation for its ability to communicate the operation of the model. This descriptive capability helps them debug the model, validate it, and then sell the validity of the model to managerial users. Unlike consultants, academics are inclined to have a mixed view toward the benefits of animation. They tend to view animation as a useful technique which must be combined with other methods for verification and validation of simulations.

**Academic Perspective.** Perhaps the most respected academic view comes from Law and Kelton. They recognize the increasing popularity of animation, but warn against overuse. They emphasize that animated output can show that a model is invalid, but cannot prove that it is valid. Caution is warranted in viewing a small segment of animated output and making optimistic generalizations about the validity of the entire simulation. They also point out the potential for problems with model elements that are not animated and therefore unobserved. For these reasons and others, Law and Kelton conclude that animation "is not a substitute for a careful statistical analysis of the simulation output (Law and Kelton, 1991:241-242).

Aiken and his colleagues at the National Center for Regional Mobility also argue that animation cannot stand alone; but, their reasons differ from Law and Kelton. Their

simulation studies involve decision makers who are not accustomed to using simulation in problem solving situations. They advocate a multimedia presentation which effectively combines text, animation, video images, and sound to enhance user understanding of the modeled system. In validation, animation is therefore only one media element and it may serve in a backup role to more effective elements such as video images or sound recordings. The key decision involves which media element or combination of elements communicates best. The primary goal is effective communication of the simulation results to decision makers. Like Law and Kelton, they stress that multimedia use "is not to replace, but to augment traditional simulation techniques and practices" (Aiken and others, 1990:775-783).

Schuppe cautions against a few pitfalls in the use of animation. He acknowledges animation's ability to improve face validity, but feels that the potential benefit should be balanced against the time it takes to develop a quality animation. Like Law and Kelton, he feels that an incomplete or inaccurate animation can give a false impression of model behavior. He cautions simulation modelers to verify their animation efforts to prevent this possibility (Schuppe, 1991:523-525).

## Current Animation Guidelines

Although the use of animation in simulation is growing, knowledge of how to effectively animate simulation output is limited. The few guidelines that exist are techniques with little or no empirical data to support their effectiveness. Tullis feels that the science of screen design is lagging behind its practice in several areas which he recommends for research. In the area of graphics, he feels that more research is required to understand when various graphical techniques provide the most effective display. When it comes to animation, Tullis sums up the need for research as follows:

> The use of animation as a screen design technique has really not even been mentioned thus far because so little is known about it. However, such techniques as moving graphical objects on the screen or introducing other time-based changes in the appearance of the screen elements can clearly have a substantial impact on the user's interpretation of the display. (Tullis, 1988:407)

Clearly, Tullis feels there is much to learn about graphics and animation and that these areas are ripe for additional research.

**Algorithm Animation Guidance.** Animation research is not limited to computer simulations. One current research approach involves techniques for animating computer algorithms. Brown and Hershberger list several existing algorithm animation techniques including the use of multiple views, state cues, static history, amount of input data, and multiple simultaneous algorithms. They suggest techniques for the use of color and sound in algorithm animations. Although they do offer limited support from human factors research, no empirical results are available to support the effectiveness of any of the suggested techniques. The authors feel that algorithm animation is a "craft, not a science". The purpose of their presentation is to inform other algorithm animators of some potentially useful techniques (Brown and Hershberger, 1991:10-17).

**Simulation Animation Guidance.** Empirical evidence on effective simulation animations is also limited. Carpenter offers some interesting animation guidelines from his recent research. He finds movement of icons to be more important than either detail or color in communicating the behavior of a simulation with moving entities. Subjects identify problems more accurately in less time when viewing moving icons, irrespective of icon color or detail. Subjects prefer animation icons with movement, detail, and color, but using the preferred animation does not result in improved objective performance. The results of this study are an important empirical justification for choosing the moving icon

display over static displays with color or detail changes (Carpenter, 1992:57). Unfortunately, significant empirical results are limited to this research.

## Display Design Research

Although guidance for animation displays is limited, display design information is available in the literature. There are several theories and practical guidelines which provide insight into how to create effective graphical and pictorial displays. Among the available theories, two that are relevant to this research are the proximity compatibility principle and the theory of emergent features. Design principles for data graphics, information displays, and the use of color in displays also provide instructive guidance. First, this review will consider the relevant display theories. Then, specific data graphics, information display, and color guidelines will be discussed.

**Display Design Theories.** There are two display design theories which may be applied to the design of effective animations. The first theory is the proximity compatibility principle. The second display design theory is emergent feature theory.

**The Proximity Compatibility Principle.** The proximity compatibility principle relates human information processing requirements to display design. According to this principle, information integration tasks benefit from displays in which elements requiring integration are related through spatial proximity, color coding, or objectness (Andre and Wickens, 1990:65). Spatial proximity requires related elements to be closely grouped and free from the clutter of unrelated elements. Color coding relates integrated elements with a common color. Objectness is the quality that related objects possess when they are closely grouped within closed contours. Each of these display characteristics can be varied to affect the display's ability to show integrated information. For focused attention tasks, the proximity compatibility principle indicates that task performance improves when display elements are separated and distinct. Displays which are used for

both integrated and focused attention tasks must balance the integration of related elements with the need to maintain their separate identities (Andre and Wickens, 1990:61-77). The appropriate balance varies with the available display elements and the associated communication tasks.

**Emergent Feature Theory.** Another display design theory which is related to the proximity compatibility theory is emergent feature theory. Emergent feature theory explains the relative communicative ability of displays for information integration tasks. An emergent feature is a meaningful pattern that is revealed in the combination of simple display elements which is not identifiable in any single or smaller group of elements (Sanderson and Buttigieg, 1991:634). The most common examples are object displays where the shape of the object is determined by more than one display parameter. Rectangular (two parameters) or triangular (three parameters) object displays indicate different display combinations with different geometric shapes.

Three descriptive components of the effectiveness of an emergent feature are faithfulness, salience, and directness. An integrated display's emergent feature should faithfully represent the pattern or patterns of interest. The emergent feature's salience is a measure of the degree to which the feature stands out or is recognizable. Directness is a measure of the correspondence between the pattern(s) of the emergent feature and the integrated information which these pattern(s) represent. Each of these components offers a way to compare alternate representations for integrating information. Integrated displays with faithful, salient, and direct emergent features are the best displays for information integration tasks (Mitchell and Biers, 1992:1503).

Mitchel and Biers offer one example of alternate display representations in an experiment based on a paradigm developed by Barnett and Wickens. They tested seven different display types to determine which display(s) were best in representing an integrated decision based on a number of weighted factors. They report superior

performance (accuracy and response time) for the faithful, salient displays which most directly represented the decision statistic. Displays which were indirect, but faithful and salient had intermediate performance. Displays which were indirect and lacked faithfulness and saliency performed the worst (Mitchel and Biers, 1989:1503-1507).

Several researchers have demonstrated that emergent features can exist in grouped bar graph displays. Coury and Purcell found information integration to be superior with a display using four grouped bar graphs than for an alternative object display. They feel the bar graphs have "configural properties that enhance the processing of multidimensional correlated data" (Coury and Purcell, 1988:1361-1365). Sanderson and others reversed an earlier experimental result in demonstrating dramatically better information integration with a redesigned three bar graph display versus a triangular object display (Sanderson and others, 1989:183-198). Mitchel and Biers showed that bar graph display design affects the resulting emergent feature of relative area with corresponding effects on integration performance (Mitchel and Biers, 1992:1503-1507). These results suggest that bar graphs can be grouped effectively to present emergent features that are superior to those in alternative object displays.

**Data Graphics Guidelines.** Unlike the previous general display theories, data graphics guidelines are only applicable to quantitative displays. Tufte has written extensively on the subject of the effective display of data graphics. He feels that extraneous lines, characters, and decorations merely clutter the graphic display and reduce the clarity of presentation. He refers to such clutter as "chartjunk" and recommends removing all extraneous material. His less is more philosophy extends to redundant information which adds little to the presentation except potential confusion. Tufte presents five fundamental principles which govern the effective visual display of quantitative information. His approach maximizes the data content of every bit of "ink" in a visual display. These principles are summarized as follows:

1) Above all else, show the data.
2) Maximize the data-ink ratio
3) Erase non-data ink
4) Erase redundant data ink
5) Revise and edit

An iterative process is necessary to scrub the quantitative display until it shows the data as clearly and succinctly as possible (Tufte, 1983:93-121).

Schmid also offers useful guidance for statistical graphics. He distinguishes column charts from bar charts because column charts have a vertical data orientation and bar charts are horizontal. One of several types of column chart is the grouped column chart. This chart has two or more data columns representing different time series or classes of data. Schmid recommends separating grouped columns with an "interspace" of approximately 25% of the column width "to facilitate grouping for comparison" (Schmid, 1983:48).

Schmid offers a few other recommendations and points out common pitfalls to avoid in column chart displays. First, he recommends distinguishing adjacent columns with even shading to avoid distracting patterns. Second, each column chart should have a zero baseline at the bottom of the chart to identify the lower range of the output scale. Third, column charts should use a rectilinear coordinate type of scale. Pitfalls to avoid include the use of multiple data scales, uneven spacing between columns, and overlapping columns. Like Tufte, Schmid stresses a simple, direct presentation to focus attention on the data and avoid confusing the user (Schmid, 1983:46-64).

**Color Graphics Guidelines.** The use of color in displays has been researched extensively. A common point of emphasis is to avoid overusing color. Murch emphasizes restricting the number of display colors that convey specific meaning to no more than six,

with three or four being preferable (Murch, 1987:2.15). He recommends bright, saturated colors to draw viewer attention, but cautions against too much color (Murch, 1990:2.15). Tufte also recommends minimizing the number of colors in an information display. He states that extraneous color yields "color clutter", a condition under which all colored objects become less distinct (Tufte, 1990:83). Tufte recommends small amounts of "strong color" against a "light gray or muted field to highlight and italicize data". He recommends background colors found in nature, especially those on the lighter side such as the yellows, blues, and grays of "sky and shadow" (Tufte, 1990:89).

## The Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a subjective assessment method for ranking alternatives. Thomas Saaty developed the process for use in complex decision making problems (Saaty, 1980). Pairwise comparisons between each alternative are used to establish the priorities of the elements of one level of a hierarchy with respect to an element of the next level. For multiple levels, priority vectors are combined into priority matrices to produce one final priority vector for the lowest level of alternatives. For single level problems, the initial priority vector ranks the individual elements (Saaty, 1980:21).

Vidulich and Tsang summarize the key advantages for the AHP. First, although more decisions are required for the AHP than for absolute estimation methods, each decision is easier to make because only two alternatives are compared at a time. Second, the relatively large number of pairwise comparisons provides redundant information which improves the reliability of the judgment. Finally, each individual's comparisons can be evaluated to determine if their judgments are consistent (Vidulich and Tsang, 1987:1058).

There are three steps required to subjectively rank alternatives using the AHP: 1) collect the judgment data, 2) construct the judgment matrix, and 3) calculate the ratings among alternatives. Judgment data includes each rater's pairwise comparisons

between alternatives. Judgments between alternative pairs are marked on a 17 slot scale where the middle slot represents no preference and marks toward the left (right) side represent increasing preference for the first (second) alternative. The analyst places numerical ratings corresponding to comparisons between alternative i and j in the upper-right cells of an n x n judgment matrix. The diagonal elements of this matrix are one and the lower-left cells are the reciprocal of the corresponding upper-right cells. Two alternative types of ratings can be calculated from this matrix. Saaty measures subjective ranking among alternatives with the normalized eigenvector for the maximum eigenvalue of the matrix. An alternative measure of subjective rank developed by Williams and Crawford compares the geometric mean of the numerical ratings from each matrix row (Vidulich, 1989:1407).

Despite the arguments of their proponents, the consensus of opinion on the alternative rating calculations finds ratings from Saaty's eigenvector method and Williams and Crawford's geometric means approach to be "very similar to each other" in most cases (Budescu and others, 1986:77). Budescu and others compared both methods and concluded that there was no clear superiority in ratings from either method (Budescu and others, 1986:77). Vidulich calculated subjective workload assessments with both methods and also found no significant differences in the subjective ratings. He feels that the "computationally simpler" geometric means approach is a viable alternative to the eigenvector method (Vidulich, 1989: 1410).

The consistency of judgment matrices is an important measure of their value in rating assessment. Vidulich defines consistent matrices as ones with "transitive trends among related judgments" (Vidulich, 1989:1407). For example, among alternatives A, B, and C, if A is preferred four times as much as B and B is preferred twice as much as C, then a consistent matrix would indicate that A is preferred eight times as much as C. For the geometric means approach, Williams and Crawford developed $S^2$ to measure the

consistency of the judgment matrix over all such transitive trends. $S^2$ equals zero under ideal consistency and "increases monotonically as the magnitude of departure from consistency increases" (Vidulich, 1989:1407).

Budescu and others used this consistency measure to develop a consistency criterion for the geometric means approach. The consistency measure is shown below.

$$S^2 = \left( \Sigma_{J=1..N} \Sigma_{K=1..N} \left[ \ln(r_{JK}) - \ln(GM_J / GM_K) \right]^2 \right) / \ (N-1)(N-2) \qquad (1)$$

where $r_{JK}$ is the pairwise comparison ratio for alternatives J and K, $GM_J$ and $GM_K$ are the geometric means of matrix rows J and K, and N is the number of alternatives in the comparison. Budescu and others conducted a Monte Carlo analysis to generate and tabulate critical values to test the null hypothesis that $S^2$ is large enough to indicate random pairwise comparisons. Under the null hypothesis, the judgment matrix is inconsistent. Calculated values for $S^2$ less than these critical values are reason to reject the null hypothesis and conclude that the judgment matrix is consistent (Budescu and others, 1986:70-73). Vidulich recommends using the geometric means method with judgment matrices of dimension 6 x 6 to 10 x 10 to ensure "reasonable applicability" of the $S^2$ critical values tabulated by Budescu and others (Vidulich, 1989:1410).

## Conclusion

Simulation model validation is a complex process. Many statistical and subjective techniques are available to convince model developers and users that the simulation model is a valid representation of reality. The essence of a valid computer simulation is its ability to mimic reality well enough so that users can make sound decisions about real systems based on data from computer experiments. Animation is gaining acceptance as one subjective validation tool that graphically depicts a model's behavior to help users

understand how well the computer model mimics the real system. More effective animations will improve this tool for future model validations.

Effective animation designs are not intuitive. Many animation users feel that animation is a communication art form that is difficult to master. Very little research exists to provide practical guidelines for the effective use of animation tools. The proximity compatibility principle and emergent feature theory offer some theoretical guidance for effective display designs. These theories must be tested in practical animation scenarios to see if they improve an animation's ability to communicate model behavior. It is only through such tests that animation's ability to enhance face validity can be shown.

Testing the effectiveness of varying animation designs yields objective and subjective measures of performance. Subjective measures consist of user preferences among competing animation designs. The Analytic Hierarchy Process is an effective tool for subjectively comparing these alternatives to rank their ability to communicate model behavior. There are several methods for calculating subjective preference ratings from judgment matrices. The eigenvalue method and the geometric means approach are examples of two popular methods which yield very similar rating results. The geometric means approach is computationally simpler and is the method which will be employed in this research.

# III. Methodology

## Research Hypothesis

Based on previous research, animations with moving icons are superior to those using color, detail, and redundant coding in communicating simulation problems involving movement of interacting entities (Carpenter, 1993:57-58). Movement was effective in highlighting relationships among these entities by displaying contrasts in their rates and frequency of motion. However, other research has indicated that dynamic bar graph displays are effective in information integration tasks (Coury and Purcell, 1988: 1365; Mitchel and Biers, 1992:1507). Their research hypothesized that dynamic bar graphs were effective displays for a system processing many similar entities. According to the stated hypothesis, an appropriately designed bar graph display can effectively integrate information from elements with a common scale of measurement. In this thesis research, bar graph and moving icon displays were used to present information about the movement of cars in a traffic network. The bar graph display was compared to a moving icon display at different presentation speeds to determine which display was more effective in integrating information on traffic movement within the network.

## Research Approach

This research examined the effects of two different animated displays and presentation speeds on an animation's ability to communicate problems in a simulation model. The animated displays included moving icons and bar graphs shown individually and in combination. All three displays were shown at two different speeds. Each displayed problem violated an explicit model assumption. Six of the problems contrasted the motion of a few entities. The other two problems involved trends in the flow of multiple entities over time. The identification of each problem required subjects to

integrate the information displayed in each type of animation. Each subject evaluated every problem scenario at one combination of animation display and presentation speed.

## Simulation Model

The Traffic Analysis model is a SLAM network simulation that models two-way traffic flow through a one-lane road segment. This model was chosen so that users could operate with a familiar and easily understandable model. The system models traffic flow from each direction to determine whether the proposed traffic signal durations make the average queue lengths approximately equal. The arrival times for cars from each direction are random variables. The relative differences in the mean arrival rates impact the optimum timing of the traffic signal in each direction (Pritsker, 1986:204-208). Figure 3.1 shows the Traffic Analysis model.

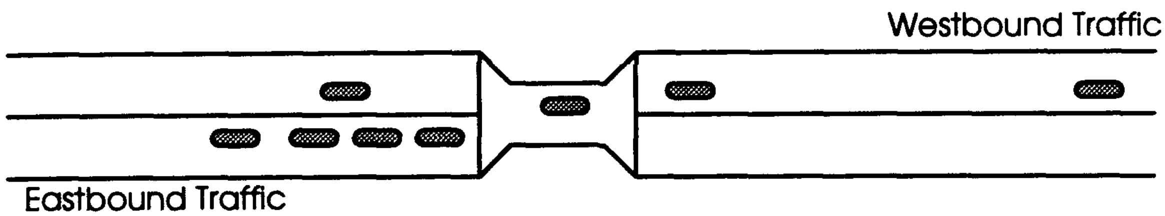



**Figure 3.1 Traffic Analysis Model**

The network code required a few modifications for animated displays of each problem. The arrival times were modeled as normal distributions to reduce traffic variability and make problems repeat at more regular intervals. Traffic light durations in each direction were also adjusted to generate average queues of moderate lengths. These changes kept queue lengths moderate so waiting cars could always be displayed on the screen. SLAM network code for each problem scenario is shown in Appendix C.

The animation commands were generated using FORTRAN subroutines. The network code accessed a given subroutine using event nodes to call event subroutines.

Each subroutine wrote animation commands to an ASCII trace file to direct changes in the animated states of individual entities and changes in summary column (vertical bar) graphs. Subroutines were necessary to create animated entities, to place them on each segment of the roadway, and to remove them from the roadway at the end of their travel. At the same time, these subroutines added increments to each column graph to indicate that an eastbound or westbound car had entered or exited the roadway system. Traffic signals for each direction were displayed with a single light which changed in the standard green-yellow-red sequence. A listing of the FORTRAN event subroutines is shown in Appendix C.

## Animations

Three different animations were required to examine moving icons and bar graphs separately and in combination. The first animation depicted a two-lane roadway with a single-lane bridge in the middle of the roadway. Icons representing cars travel the roadway, stopping at the narrow bridge segment when the light is red. Marks were placed on the roadway to serve as queue length reference points. This animation was referred to as the "Cars" animation. The second animation created three bar graphs for each direction to indicate the total number of cars on each roadway segment. Each bar graph also had queue length reference marks. In addition, each direction had a bar graph to indicate interarrival time between cars. This animation was referred to as "Bars". The final animation was a combination of the first two. This animation was referred to as "Cars & Bars". A picture of each of the animation elements is included in Appendix A.

Each animation was created using Proof Animation Version 1.1. A layout file for each animation created the background display. The background display for each animation included all the permanent elements. A trace file for each animation generated the dynamic elements of each display. Each combination of animation and presentation

speed required a unique layout file. Therefore there were six layout files in the experiment. Each problem scenario required a unique trace file generated from the underlying simulation. Therefore there were eight unique trace files in the experiment for each animation.

## Problem Scenarios

There were eight unique problem scenarios created for this experiment. Although each problem was unique, the eight problems fit into two categories: 1) problems visible in the motion of one (or a few) cars and 2) problems visible in the flow of many cars. Table 3.1 gives a brief description of each problem scenario along with its category.

Each problem required changes in the network code. Problem one had all cars delay in the traffic light queue. Problem two had shorter event times for travel on each roadway segment. Problem three had closely-spaced arrivals for both traffic directions. Problem four had the light change event occur after traffic left the arrival queue. Problem five changed the westbound arrival distribution to a constant value. Problem six required a change in the event timing for westbound travel on the outbound leg. Problem seven had a greater arrival rate for westbound cars which was not compensated by light timing. Finally, problem eight had changes in event timing to allow two-way traffic on the bridge. Network code for each of the problem scenarios is shown in Appendix C.

## Experimental Design

The experiment had objective results and subjective results. The objective results considered problem identification response times and identification accuracy. The subjective results considered subjective ratings among animated presentations.

**Table 3.1 Problem Scenarios**

| Problem Number / Title | Category 1 / 2 | Description of Problem |
|---|---|---|
| 1) Cars Pause | 1 | Each car briefly stops at a green light before proceeding |
| 2) Car Speeds Differ | 1 | Cars from one direction travel through the system twice as fast as cars from the opposite direction. |
| 3) Encroachment | 1 | Cars enter the system with interarrival times that are insufficient to provide physical separation. |
| 4) False Start | 1 | The first car waiting at a red light moves onto the bridge before the light turns green. |
| 5) Constant Arrival | 2 | Cars enter the system at a constant rate when they should have random interarrival times |
| 6) Exit Queue | 1 | Cars from one direction form an exit queue while waiting to leave the outbound road segment. |
| 7) Long Average Queue | 2 | The average queue lengths of cars from each direction are distinctly different. |
| 8) Two-way traffic | 1 | Traffic light sequencing allows two-way traffic on the bridge. |

**Model Description (Objective Results).** This experiment employed a 3 x 2 x 8 factorial design ( Animated Display x Presentation Speed x Problem Scenario ) with repeated measures on the third factor ( problem scenario ). Each subject viewed all problem scenarios, but only one combination of the animated display and presentation

speed factors. The structural model on which the design is based is as follows (Winer and others, 1991:548):

$$Y_{IJKM} = \mu + \alpha_I + \beta_J + \alpha\beta_{IJ} + \pi_{M(IJ)} + \gamma_K + \alpha\gamma_{IK} + \beta\gamma_{JK} + \alpha\beta\gamma_{IJK} + \gamma\pi_{KM(IJ)} + \varepsilon_{O(IJKM)} \tag{2}$$

where:

| | |
|---|---|
| $Y_{IJKM}$ | is the response time of the mth subject for treatment levels i,j,k |
| $\mu$ | is the overall mean response time |
| $\alpha_I$ | is the ith treatment effect for presentation speed display factor |
| $\beta_J$ | is the jth treatment effect for animation type factor |
| $\alpha\beta_{IJ}$ | is the i-jth interaction effect of the speed / animation factors |
| $\pi_{M(IJ)}$ | is the nested effect of subject m under the ith level of speed and the jth level of animation |
| $\gamma_K$ | is the kth treatment effect for problem scenario |
| $\alpha\gamma_{IK}$ | is the i-kth interaction effect of the speed / problem factors |
| $\beta\gamma_{JK}$ | is the j-kth interaction effect of the animation / problem factors |
| $\alpha\beta\gamma_{IJK}$ | is the i-j-kth interaction effect of speed/animation/problem |
| $\gamma\pi_{KM(IJ)}$ | is the k-mth interaction of problem and subject under treatment levels i, j for speed/animation factors |
| $\varepsilon_{O(IJKM)}$ | is the experimental error nested within each observation |

Subjects are nested under the first two factors ( animation display and presentation speed). Therefore, the model assumes no interaction between these factors and the subject factor. The design factors ( animation display, presentation speed, and problem scenario) are fixed factors.

The dependent variable is the elapsed simulated time that the subject views each scenario before a problem is noted. This elapsed time is displayed in the animation

window. The elapsed time stops anytime the animation is stopped. The rate of change of elapsed time is directly proportional to the speed of presentation.

**Model Validation.** Validation of the within-subjects design requires statistical tests for the homogeneity of between-subject effects and within-subject effects. Winer recommends homogeneity tests using the ratio of the maximum sums of squares over the minimum sums of squares for each of these variance components. These ratios are compared to critical values of the $F_{max}$ statistic. Degrees of freedom for the numerator are the number of sum of square components being compared. Degrees of freedom for the denominator are the number of observations used to form each sum of square component. The null hypothesis of homogeneity is rejected if the maximum over minimum sum of squares ratio is larger than $F_{max}$ (Winer and others, 1991:550-551).

The repeated measures model also assumes that covariance matrices computed over the levels of the repeated factor for each group of subjects are homogeneous with a pooled common matrix which is circular (Winer and others, 1991: 551). Keppel notes that this assumption is frequently violated in behavioral research. He questions the applicability of statistical computer tests of this assumption because such tests have "assumptions of their own that complicate any interpretation of their outcomes" (Keppel, 1991:351).

Keppel recommends a conservative approach which assumes the covariance matrices are not homogeneous and adjusts the degrees of freedom in the overall F-tests to guard against positive error bias (Keppel, 1991: 465). Winer also recommends the conservative F-test whenever the assumption of homogeneous covariance matrices is "questionable" (Winer and others, 1991:551). In light of these recommendations, the analysis assumed that the covariance matrices were heterogeneous and adopted the conservative F-test.

The conservative approach reduces the numerator and denominator degrees of freedom for the F-test statistic by a factor of $r-1$ where $r = 8$ is the number of levels of the repeated factor. The resulting overall F-tests are negatively biased (conservative) because the real level of significance will exceed the nominal p-value (Winer and others: 253).

**Randomization Scheme.** Each subject was randomly assigned to view one of the six combinations of display and presentation speed. Problem scenarios were presented in a randomized order to each subject to minimize treatment order and carry-over effects. For example, the first subject viewed the bar graph animation display at the faster presentation speed. This subject viewed all eight problem scenarios in the random sequence 2-5-3-7-6-1-8-4. The randomized design for each subject is shown in Table 3.2.

**Model Description (Subjective Results).** The subjective Analytic Hierarchy Process (AHP) ratings were evaluated using a two-factor repeated measures analysis of variance model. Each subject viewed all six combinations of presentation speed and animation type. For this analysis of variance, the numerical AHP ratings were the dependent variable. The independent variables were animation presentation and presentation speed. The structural model on which the design is based is as follows (Keppel, 1991:461-478):

$$\begin{aligned} \mathbf{Y}_{\mathbf{IJK}} = \mu + \alpha_I + \beta_J + \alpha\beta_{IJ} + \pi_K + \alpha\pi_{IK} \\ + \beta\pi_{JK} + \alpha\beta\pi_{IJK} + \varepsilon_{M(IJK)} \end{aligned} \qquad (3)$$

where:

| | |
|---|---|
| $\mathbf{Y}_{\mathbf{IJK}}$ | is the AHP rating of the mth subject for treatment levels i,j |
| $\mu$ | is the overall mean AHP rating |

$\alpha_I$ is the ith treatment effect for animation display factor

$\beta_J$ is the jth treatment effect for presentation speed factor

$\alpha\beta_{IJ}$ is the i-jth interaction effect of the display / speed factors

$\pi_K$ is the effect of subject k

$\alpha\pi_{IK}$ is the interaction of the ith display treatment effect and the effect of subject k

$\beta\pi_{JK}$ is the interaction of the jth speed treatment effect and the effect of subject k

$\alpha\beta\pi_{IJK}$ is the interaction of the ith display and jth speed treatment effects and the effect of subject k

$\varepsilon_{M(IJK)}$ is the experimental error nested within each observation

**Model Validation.** Validation of the two-factor within-subjects design requires statistical tests for the homogeneity of each of the three within-subject effects. The within-subject homogeneity tests also use the ratio of the maximum sums of squares over the minimum sums of squares. This ratio is compared to critical values of the $F_{max}$ statistic. Degrees of freedom for the numerator are the number of sum of square components being compared. Degrees of freedom for the denominator are the number of observations used to form each sum of square component. The null hypothesis of homogeneity is rejected if the maximum over minimum sum of squares ratio is larger than $F_{max}$ (Winer and others, 1991:550-551).

The two-factor within subjects design also assumes that covariance matrices computed over the levels of the repeated factors for each group of subjects are homogeneous with a pooled common matrix which is circular. Once again, the covariance matrices were assumed to be heterogeneous. The conservative degrees of freedom for the F-test statistic were 1 and n-1, where n equals the number of subjects in the experiment. These degrees of freedom were used for all overall F-tests (Keppel, 1991:465).

**Randomization Scheme.** Each subject viewed each of the six combinations of display and presentation speed in a randomized order to minimize treatment order and carry-over effects. The random sequences for each subject are shown in Table 3.3. The slower speed presentations of the combined, bar graph, and car icon animations are coded SA, SB, and SC. The faster speed presentations of the combined, bar graph, and car icon animations are coded FA, FB, and FC.

## Subjects

Fifty-four subjects from the Air Force Institute of Technology (graduate students and faculty) were evaluated in the experiment. All subjects had course work in probability and statistics and an understanding of random variables. All subjects were unpaid volunteers. No prior experience with simulation or animation was required.

## Apparatus

The animation was displayed using Wolverine Software Corporation's Proof Animation Version 1.1. This software is a general purpose, post-processing animation that operates with ASCII commands generated from the simulation program. Display of this animation software requires an 80286 (or better) processor, a math co-processor (or processors with built-in math), EGA or VGA video adapter and display, and at least 256K of video memory. The experiment was completed on a 486DX/2-50 CPU, using a 14" VGA monitor to satisfy the hardware requirements. The subjects viewed the display and were not required to operate the system.

**Table 3.2 Experimental Design ( Objective Results )**

| Run # | Animation Type | Presentation Speed | Problem Sequence |
|---|---|---|---|
| 1 | Bars | Fast | 2-5-3-7-6-1-8-4 |
| 2 | Bars/Cars | Fast | 2-6-4-8-7-3-1-5 |
| 3 | Bars | Slow | 4-6-1-3-5-7-2-8 |
| 4 | Bars/Cars | Slow | 5-7-6-1-3-2-4-8 |
| 5 | Cars | Slow | 4-5-6-2-1-8-7-3 |
| 6 | Cars | Fast | 2-5-4-6-7-8-3-1 |
| 7 | Bars/Cars | Fast | 5-4-2-6-7-3-1-8 |
| 8 | Cars | Fast | 6-5-1-7-4-8-2-3 |
| 9 | Cars | Slow | 2-3-7-5-4-1-8-6 |
| 10 | Bars | Slow | 5-1-8-2-3-4-6-7 |
| 11 | Bars/Cars | Slow | 5-2-1-7-6-8-3-4 |
| 12 | Bars | Fast | 2-8-1-6-7-3-5-4 |
| 13 | Bars | Slow | 5-3-7-1-2-6-4-8 |
| 14 | Cars | Fast | 4-8-3-6-2-1-7-5 |
| 15 | Cars | Slow | 6-1-4-3-2-5-7-8 |
| 16 | Bars/Cars | Slow | 1-4-7-5-8-6-3-2 |
| 17 | Bars/Cars | Fast | 2-7-6-5-3-1-4-8 |
| 18 | Bars | Fast | 2-8-1-6-4-5-3-7 |
| 19 | Bars/Cars | Fast | 7-8-4-3-1-6-2-5 |
| 20 | Bars | Fast | 3-5-8-2-6-7-4-1 |
| 21 | Cars | Slow | 4-8-3-6-5-2-7-1 |
| 22 | Cars | Fast | 8-6-3-4-7-1-2-5 |
| 23 | Bars/Cars | Slow | 5-8-4-1-7-6-3-2 |
| 24 | Bars | Slow | 6-8-7-4-1-2-3-5 |
| 25 | Bars | Fast | 4-8-5-7-2-3-6-1 |
| 26 | Cars | Slow | 7-2-5-3-1-4-8-6 |
| 27 | Bars | Slow | 6-8-7-2-1-5-3-4 |
| 28 | Cars | Fast | 6-5-4-8-7-3-2-1 |
| 29 | Bars/Cars | Fast | 3-5-4-8-7-2-1-6 |
| 30 | Bars/Cars | Slow | 4-1-3-6-2-8-5-7 |
| 31 | Cars | Slow | 6-3-8-5-2-4-1-7 |
| 32 | Cars | Fast | 6-3-4-7-5-2-8-1 |
| 33 | Bars/Cars | Fast | 1-8-2-5-3-7-4-6 |
| 34 | Bars/Cars | Slow | 6-8-5-7-4-1-3-2 |
| 35 | Bars | Fast | 4-5-3-8-7-2-1-6 |
| 36 | Bars | Slow | 8-2-4-7-6-1-3-5 |

**Table 3.2 Experimental Design ( Objective Results ) (continued)**

| Run # | Animation Type | Presentation Speed | Problem Sequence |
|---|---|---|---|
| 37 | Bars | Slow | 2-4-3-7-6-1-8-5 |
| 38 | Bars | Fast | 3-7-8-2-6-1-4-5 |
| 39 | Cars | Slow | 5-2-7-6-8-1-3-4 |
| 40 | Bars/Cars | Fast | 1-8-4-3-6-5-7-2 |
| 41 | Bars/Cars | Slow | 7-2-3-5-8-4-6-1 |
| 42 | Cars | Fast | 6-4-7-8-3-2-5-1 |
| 43 | Bars | Fast | 4-2-6-3-5-7-1-8 |
| 44 | Bars | Slow | 6-3-7-1-5-2-8-4 |
| 45 | Cars | Slow | 8-6-2-4-1-5-7-3 |
| 46 | Bars/Cars | Fast | 8-4-6-5-3-1-7-2 |
| 47 | Bars/Cars | Slow | 3-1-8-4-2-6-5-7 |
| 48 | Cars | Fast | 2-1-6-8-4-5-7-3 |
| 49 | Cars | Fast | 5-1-3-7-8-4-6-2 |
| 50 | Cars | Slow | 2-6-4-8-1-7-3-5 |
| 51 | Bars | Slow | 4-7-6-5-8-3-2-1 |
| 52 | Bars | Fast | 8-4-6-2-1-3-7-5 |
| 53 | Bars/Cars | Slow | 2-3-6-8-5-7-4-1 |
| 54 | Bars/Cars | Fast | 3-1-4-8-5-6-7-2 |

## Training Materials

Although the experimental model was familiar to most subjects, training sheets were presented to reinforce the model assumptions and clarify the presentation mode for each animated display. Each of the model assumptions was listed on the sheet. These training sheets explained the subject's role in viewing the animations for a violation of model assumptions. Training sheets also explained the display elements of the animation so the subject knew how the data was represented in each display. Examples of the training sheets are given in Appendix A.

**Table 3.3 Experimental Design ( Subjective Results )**

| Run # | Viewing Sequence | Run # | Viewing Sequence |
|---|---|---|---|
| 1 | SB-FB-SC-FC-SA-FA | 28 | FC-FB-FA-SC-SB-SA |
| 2 | SB-FC-FA-SC-SA-FB | 29 | SC-FB-FA-SB-SA-FC |
| 3 | FA-FC-SA-SC-FB-SB | 30 | FA-SA-SC-FC-SB-FB |
| 4 | FB-FC-SA-SC-SB-FA | 31 | FC-SC-FB-SB-FA-SA |
| 5 | FA-FB-FC-SB-SA-SC | 32 | FC-SC-FA-FB-SB-SA |
| 6 | SB-FB-FA-FC-SC-SA | 33 | SA-SB-FB-SC-FA-FC |
| 7 | FB-FA-SB-FC-SC-SA | 34 | FC-FB-FA-SA-SC-SB |
| 8 | FC-FB-SA-FA-SB-SC | 35 | FA-FB-SC-SB-SA-FC |
| 9 | SB-SC-FB-FA-SA-FC | 36 | SB-FA-FC-SA-SC-FB |
| 10 | FB-SA-SB-SC-FA-FC | 37 | SB-FA-SC-FC-SA-FB |
| 11 | FB-SB-SA-FC-SC-FA | 38 | SC-SB-FC-SA-FA-FB |
| 12 | SB-SA-FC-SC-FB-FA | 39 | FB-SB-FC-SA-SC-FA |
| 13 | FB-SC-SA-SB-FC-FA | 40 | SA-FA-SC-FC-FB-SB |
| 14 | FA-SC-FC-SB-SA-FB | 41 | SB-SC-FB-FA-FC-SA |
| 15 | FC-SA-FA-SC-SB-FB | 42 | FC-FA-SC-SB-FB-SA |
| 16 | SA-FA-FB-FC-SC-SB | 43 | FA-SB-FC-SC-FB-SA |
| 17 | SB-FC-FB-SC-SA-FA | 44 | FC-SC-SA-FB-SB-FA |
| 18 | SB-SA-FC-FA-FB-SC | 45 | FC-SB-FA-SA-FB-SC |
| 19 | FA-SC-SA-FC-SB-FB | 46 | FA-FC-FB-SC-SA-SB |
| 20 | SC-FB-SB-FC-FA-SA | 47 | SC-SA-FA-SB-FC-FB |
| 21 | FA-SC-FC-FB-SB-SA | 48 | SB-SA-FC-FA-FB-SC |
| 22 | FC-SC-FA-SA-SB-FB | 49 | FB-SA-SC-FA-FC-SB |
| 23 | FB-FA-SA-FC-SC-SB | 50 | SB-FC-FA-SA-SC-FB |
| 24 | FC-FA-SA-SB-SC-FB | 51 | FA-FC-FB-SC-SB-SA |
| 25 | FA-FB-SB-SC-FC-SA | 52 | FA-FC-SB-SA-SC-FB |
| 26 | SB-FB-SC-SA-FA-FC | 53 | SB-SC-FC-FB-FA-SA |
| 27 | FC-SB-SA-FB-SC-FA | 54 | SC-SA-FA-FB-FC-SB |

## Experimental Procedure

First, subjects reviewed the training sheet which explained model assumptions and the animated presentation they were about to view. After this review, a nominal animation was shown to give each subject a picture of the system in operation. The researcher narrated the animation from a prepared script to review model assumptions and describe

animated elements. At this point, the researcher answered any final questions relating to model assumptions or animated presentation.

Each subject then viewed the eight problem scenarios in the predetermined random order ( Table 3.2). Total viewing time varied with speed of presentation because the faster presentation speed displayed each problem scenario twice as fast as the slower speed presentation. Animations at the slower presentation speed could be viewed for a maximum of two minutes. Animations at the faster presentation speed could be viewed for a maximum of one minute. The subject indicated problem identification by saying "stop". At this point, the researcher stopped the presentation and the subject identified the problem. When a problem was identified, the elapsed simulated time was recorded as a measure of problem response time. If the subject did not attempt to identify a problem, the total elapsed simulation time was recorded as problem response time. Problem identification accuracy was also recorded.

After the problem scenarios were complete, each subject was shown randomly-ordered 30 second presentations of each combination of animation type and speed. The pairwise comparison procedure was explained and each subject made pairwise preference comparisons between the six combinations of animation type and presentation speed. The subjective ratings concluded the experiment. The total time required for each subject's participation was 35 to 40 minutes.

## Data Collection Forms

The first form was for response data from each subject. Response data included the time required to identify a problem scenario and the identification accuracy. Since each subject viewed all eight problems, there were eight response times and eight identification accuracy data records on each form. An example of this data collection form is given in Appendix A.

A second set of forms were used to record the subjective pairwise comparisons of the various combinations of animation presentation and speed. Pairwise comparison instructions and a list of all the animation combinations were on the first page. The second page included several example comparisons. The third page was a blank form which contained all 15 pairwise comparisons required from each subject. Each comparison line had 17 blanks with the middle blank indicating no preference between alternatives and blanks to either side indicating increasing levels of preference for alternatives on either side. An example of these subjective preference forms is included in Appendix A.

The final data collection form is the pairwise matrix form. This form was used to record each subject's pairwise rankings in a matrix. The resulting matrix was used to calculate each subject's Analytic Hierarchy Preference ratings for each of the six animation presentations. The $S^2$ consistency measure was calculated from the data matrix and recorded on this form. An example of a completed pairwise matrix form is shown in Appendix A.

## Data Analysis

There were two data analysis efforts: one for the objective response data and another for the subjective preference ratings. The response data was analyzed using the three-factor analysis of variance model (Equation (2)) to determine if there were significant effects due to each of the factors and their interactions. The contrast between problem types one and two was also examined to see if problem type affected response time.

Subjective ratings for the pairwise Analytic Hierarchy Process (AHP) comparisons were calculated using the SWORD computer program provided by Vidulich (SWORD, 1989). This program calculated each subject's AHP ratings for the animation

combinations and also calculated a consistency measure. The AHP ratings included normalized maximum eigenvalues and normalized geometric means. Normalized geometric means were used as the measure of subjective preferences for the two-factor analysis of variance model (Equation (3)). The $S^2$ consistency measure was compared to its critical value to test for consistency in each subject's comparisons. Inconsistent preference ratings were excluded from the analysis.

# IV. Results

Fifty-four AFIT students and faculty completed the animation experiment. The data included objective performance measures and subjective preference ratings. The analysis of the objective and subjective data was conducted separately. The objective analysis included an evaluation of subjects' response time and identification accuracy for each problem. The subjective analysis evaluated subjects' pairwise comparison ratings for the six different animated presentations. The objective analysis is first.

## Objective Results

**Summary of Results.** Response times were measured in seconds of simulated time. This scale was common for both presentation speeds. The slower speed animations had a maximum viewing time of two minutes because four seconds of simulation output were displayed in each second of the animation. The faster speed animations had a maximum viewing time of one minute because eight seconds of simulation output were shown in each second of the animation. At either speed, response times measured the amount of simulation output subjects viewed before they were ready to identify a problem.

Each subject viewed all eight problems under one combination of animation display and presentation speed. Figure 4.1 shows the mean response times (RT) at each of the six combinations of animation type and presentation speed. The first three bars represent the slower speed presentations of car icons and bar graphs (SA), bar graphs only (SB), and car icons only (SC). The next three bars represent the faster speed presentations of car icons and bar graphs (FA), bar graphs only (FB), and car icons only (FC). The mean response times for each type of animation were shorter when they were viewed at the slower presentation speed. Subjects viewed less simulation output at the slower presentation speed prior to making their responses.

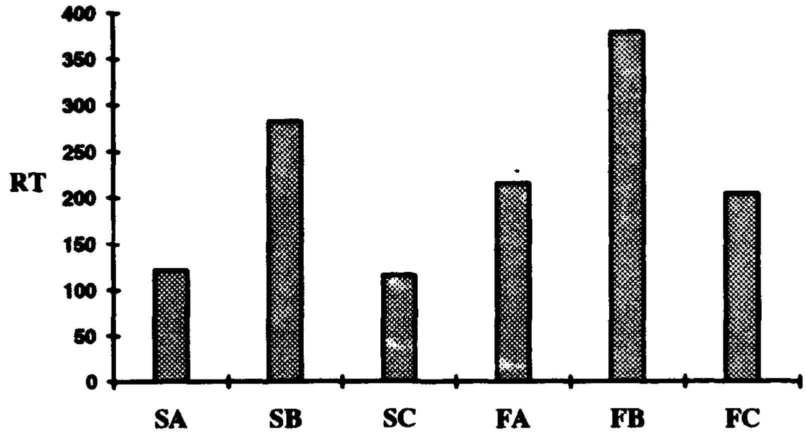



**Figure 4.1 Mean Response Time for Animated Presentations**

Mean response times (RT) also varied by problem (see Table 3.1, Chapter 3 for problem definitions). Figure 4.2 shows the average response time for each of the eight problems presented in the experiment. Response times were similar for most problems. Problem three had the shortest response time and problem five had the longest. The significance of these differences is addressed in the ANOVA for response time.

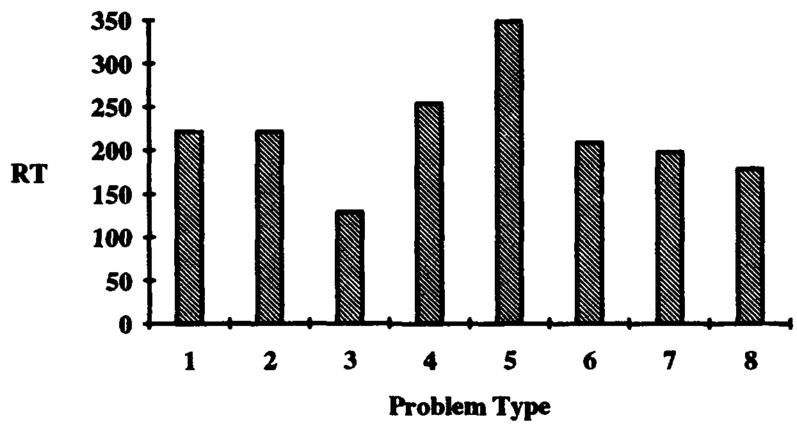



**Figure 4.2 Mean Response Time by Problem Type**

Accuracy of problem identification also varied with the type of animation, speed of presentation, and problem type. For a description of each problem, see Table 3.1 in the previous chapter. Figure 4.3 shows the accuracy of problem identification at each presentation speed for all three animation types. Identification accuracy was lowest for problem five and highest for problem three. With the exception of problem four, identification accuracy was similar at both presentation speeds.

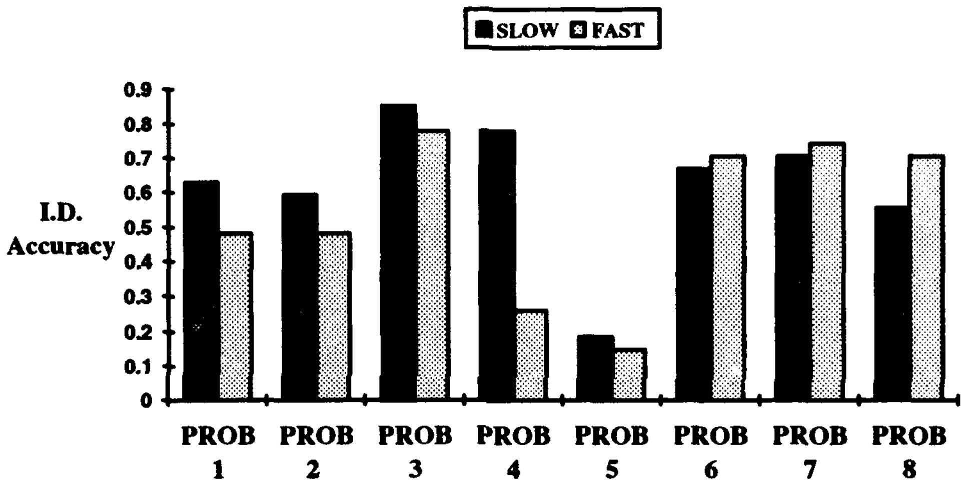



**Figure 4.3 Mean Accuracy by Problem / Presentation Speed**

Figure 4.4 shows the problem identification accuracy for each type of animation at both presentation speeds. Missing columns indicate animation types with no accurate problem identifications. There were no accurate identifications of problems one or two for the bar graph animation and none for problem five with the car icon animation. For a description of each problem, see Table 3.1 in the previous chapter. For most problems, identification accuracy with the combined (car icons and bar graphs) and the car icon animations was higher than accuracy with the bar graph animation.

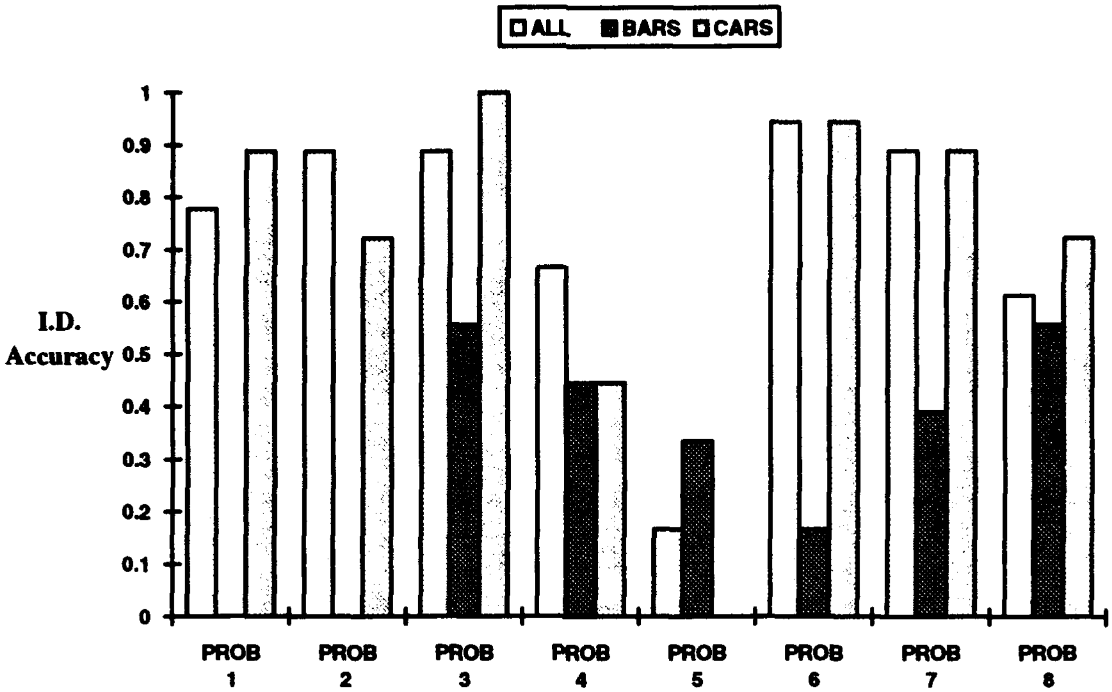



**Figure 4.4 Mean Accuracy by Problem / Animated Presentation**

Figures 4.5 - 4.12 show problem identification accuracy for each combination of animation and speed of presentation. Once again, missing columns indicate combinations of speed and animation at which no problem was accurately identified. For most problems, both the combined (car icon and bar graph) and the car icon animations have higher identification accuracy at both presentation speeds than the bar graph animation. The exception is problem five, where bar graph identification accuracy at both presentation speeds equals or exceeds the accuracy for the other two animations.

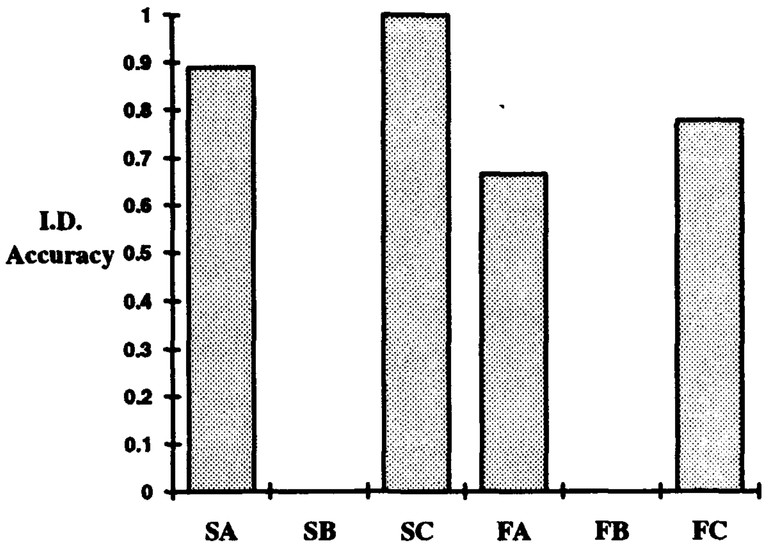



**Figure 4.5 Mean Accuracy by Speed / Animation**
**( Problem One: Cars Pause )**

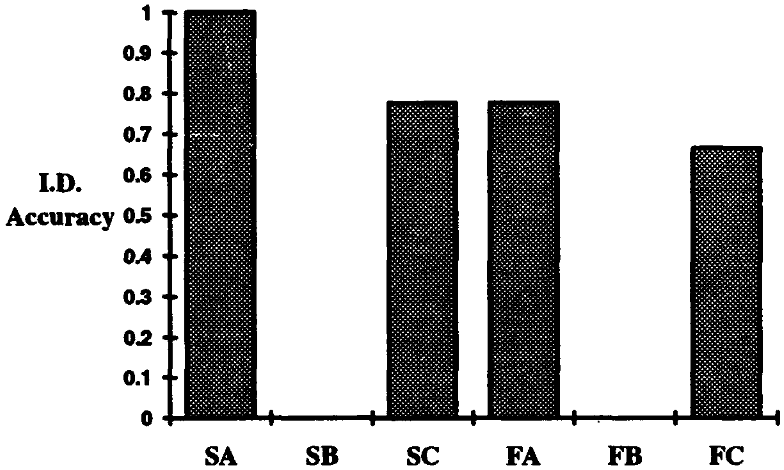



**Figure 4.6 Mean Accuracy by Speed / Animation**
**( Problem Two: Car Speeds Differ )**

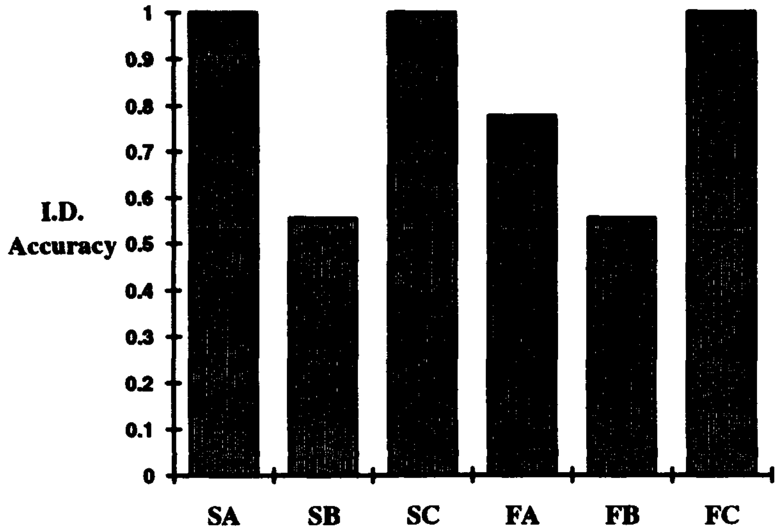



**Figure 4.7 Mean Accuracy by Speed / Animation
( Problem Three: Encroachment )**

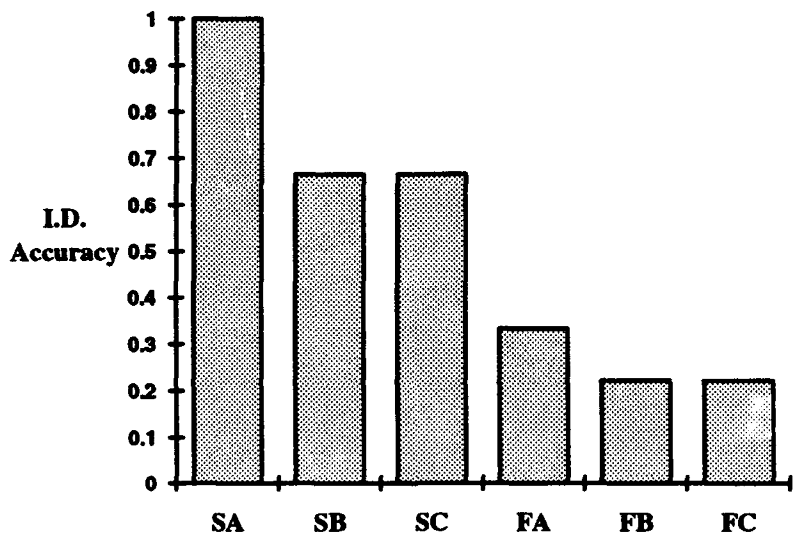



**Figure 4.8 Mean Accuracy by Speed / Animation
( Problem Four: False Start )**

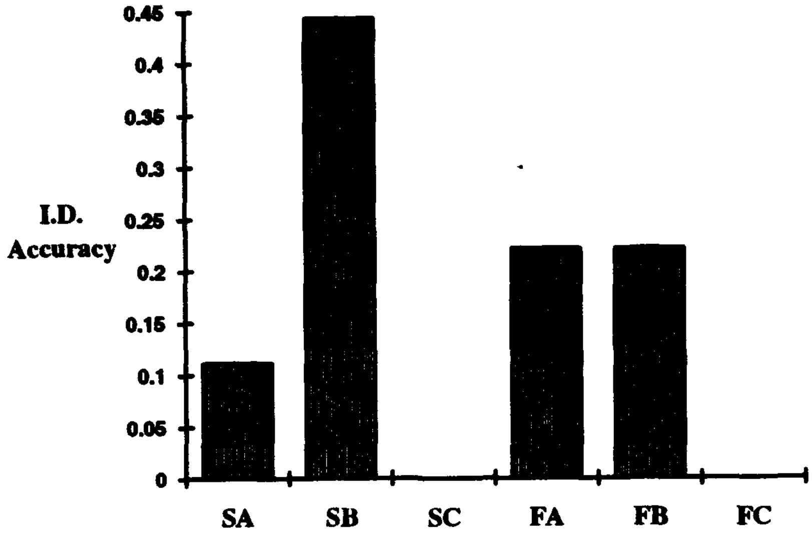



**Figure 4.9 Mean Accuracy by Speed / Animation**
**( Problem Five: Constant Arrival )**

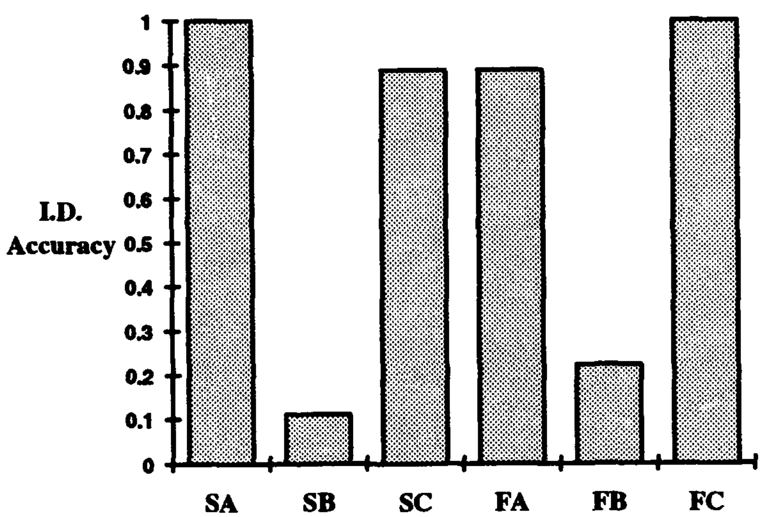



**Figure 4.10 Mean Accuracy by Speed / Animation**
**( Problem Six: Exit Queue )**

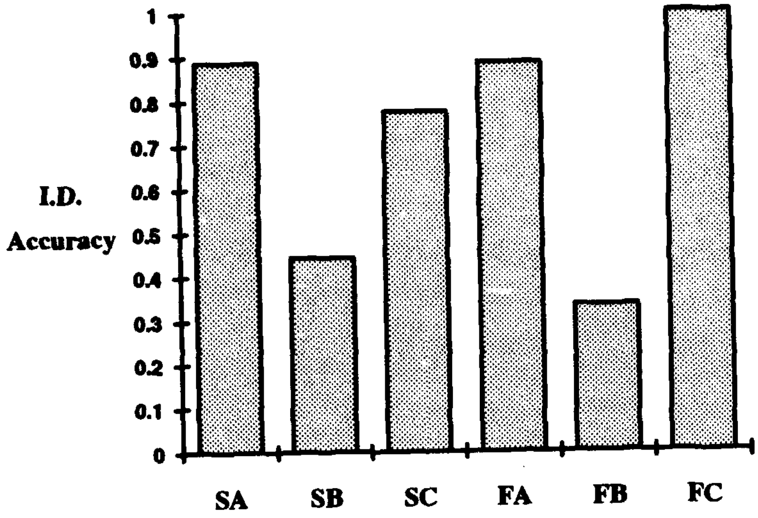



**Figure 4.11 Mean Accuracy by Speed / Animation ( Problem Seven: Long Avg. Queue )**

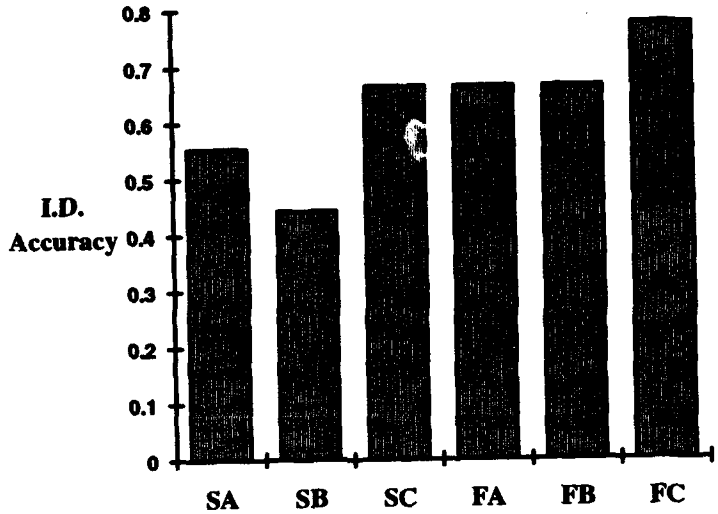



**Figure 4.12 Mean Accuracy by Speed / Animation ( Problem Eight: Two-way Traffic )**

**ANOVA for Response Time.** This analysis of variance assumed a three-factor repeated measures design. The three factors included presentation speed, animation type, and problem type. Problem type was the repeated factor viewed by all subjects. Subjects are a random factor which interacts with problem only since the presentation speed and animation type factors are nested within subjects.

**Model Validation.** The significance of the ANOVA results depend on the validity of the model. The repeated measures model assumes all sources of variation are homogeneous. For the response time model, sources of variation include between-subjects and within-subjects effects (Winer and others, 1991: 550-551).

First, the homogeneity of the between-subjects variation was tested. The variation due to differences between subjects was partitioned by speed of presentation and type of animation into six groups. The homogeneity of this error was tested with Hartley's $F_{max}$ test. The null hypothesis assumes homogeneous variance for all six between-subjects components. Hartley's $F_{max}$ test failed to reject the null hypothesis at a significance level of $\alpha = .05$. The results are shown in Table 4.1

**Table 4.1 Between-Subject Variance Homogeneity Test**
**( Response Time ANOVA )**

| Homogeneity Test | DF | Test Statistic | Critical Value | P- Value |
|---|---|---|---|---|
| Hartley's $F_{max}$ | 6 , 8 | 3.715 | 9.03 | $\gg > .05$ |

Next, the homogeneity of the within-subjects variation was tested. The variation due to differences within groups of subjects for the repeated factor (problem) was again partitioned into the six groups. The homogeneity of this error was also tested with Hartley's $F_{max}$ test. This test also failed to reject the null hypothesis of homogeneous error at a significance level of $\alpha = .05$. The results are shown in Table 4.2.

**Table 4.2 Within-Subject Variance Homogeneity Test
( Response Time ANOVA )**

| Homogeneity Test | DF | Test Statistic | Critical Value | P- Value |
|---|---|---|---|---|
| Hartley's $F_{max}$ | 6 , 56 | 2.20 | 2.22 | > .05 |

According to Winer and others, the experimenter should consider a transformation on the response variable if either error term proves to be heterogeneous (Winer and others, 1991: 551). Although the within-subject variance homogeneity test was marginal, a transformation on the response variable was not required.

**Overall F-Tests.** The ANOVA results are summarized in Table 4.3. Significant effects include speed of presentation, type of animation, type of problem, and the two-way interaction of type of animation with type of problem. Degrees of freedom for the computation of mean sums of squares are shown in the table. Degrees of freedom for all tests involving the repeated factor are table values divided by r-1 where r = 8 are the levels of the repeated (problem) factor.

**Simple Effects F-Tests.** The interaction between animation and problem factors was examined using the effect of animation at each level of problem. The numerator of each F ratio was the mean sum of squares for animation at each level of problem. The error term in the denominator of each F ratio was a weighted average of the mean square errors between and within subjects.

**Table 4.3 Summary ANOVA for Response Time**

| SOURCE | DF | SS | MS | F | P-VALUE |
|---|---|---|---|---|---|
| Between | Subjects | | | | |
| SPEED | 1 | 945378.9 | 945378.9 | 30.16 | .0001 |
| ANIMATION | 2 | 2690407.4 | 1345203.7 | 42.92 | .0001 |
| SPEED x ANIMATION | 2 | 804.7 | 402.4 | .01 | .9872 |
| ERROR BETWEEN | 48 | 1504530.3 | 31344.4 | | |
| Within | Subjects | | | | |
| PROBLEM | 7 | 1532057.9 | 218865.4 | 13.88 | .0005 |
| SPEED x PROBLEM | 7 | 80937.7 | 11562.5 | .73 | .3971 |
| ANIMATION x PROBLEM | 14 | 1010550.7 | 72182.2 | 4.58 | .0151 |
| SPEED x ANIMATION x PROBLEM | 14 | 207673.7 | 14833.8 | .94 | .3977 |
| ERROR WITHIN | 336 | 5299856.4 | 15773.4 | | |

For the simple effect F-test of animation at each problem level ( B at $C_k$ ), the following denominator was used (Winer and others, 1991: 550).

$$\text{F-ratio Denominator} = \frac{[(\ MS_{error(between)} + (\ MS_{error(within)}\ )*(r-1)\ )]}{r} \qquad (4)$$

where r = levels of repeated factor = 8

The degrees of freedom for the denominator of each F ratio were calculated using the following Satterthwaite approximation (Winer and others, 1991:537).

$$df \cong \frac{[\ MS_{error(betw)} + (r-1)*MS_{err(within)}\ ]^2}{MS^2_{err(betw)} / (p*(q-1)*(n-1)) + ((r-1)*MS_{err(within)})^2 / (p*(q-1)*(n-1)*(r-1))} \qquad (5)$$

where $r$ = # of levels of repeated factor (problem)

$p, q$ = # of levels of between-subjects factors ( speed, animation)

$n$ = # of subjects viewing each animated presentation

Test results for each simple main effect are shown in Table 4.4 The null hypothesis assumes that animation type has no effect on response time at each level of problem. The data for problems five, seven and eight indicate there were no significant differences in mean response time between animations for these three problems. The simple main effect for animation was significant for problems one through four and problem six, indicating that the type of animation significantly affected response time for these problems. Animation type did not significantly affect response time for problems five, seven, and eight.

Figure 4.13 is a plot of the interaction between animation and problem type. This plot shows that animation type has a significant effect on response time for problems one, two, three, four, and six (shown with solid lines). Animation type does not significantly affect response time for problems five, seven, and eight. These problems are shown with dashed lines.

**Table 4.4 Simple Effects of Animation for Each Problem**

| SOURCE | DF | SS | MS | F | P-VALUE |
|---|---|---|---|---|---|
| ANIMATION at PROBLEM 1 ( Cars Pause ) | 2 | 839796. | 419898.0 | 23.7 | .0000 |
| ANIMATION at PROBLEM 2 ( Car Speeds Differ) | 2 | 1098857.2 | 549428.6 | 31.0 | .0000 |
| ANIMATION at PROBLEM 3 ( Encroachment ) | 2 | 314345.2 | 157172.6 | 8.87 | .0002 |
| ANIMATION at PROBLEM 4 ( False Start | 2 | 161396.0 | 80698.0 | 4.55 | .0112 |
| ANIMATION at PROBLEM 5 ( Constant Arrival ) | 2 | 45033.8 | 22516.9 | 1.27 | .2816 |
| ANIMATION at PROBLEM 6 ( Exit Queue ) | 2 | 1121233.0 | 560616.5 | 31.64 | .0000 |
| ANIMATION at PROBLEM 7 (Long Avg. Queue) | 2 | 75215.4 | 37607.4 | 2.12 | .1193 |
| ANIMATION at PROBLEM 8 ( Two-way Traffic ) | 2 | 45081.4 | 22540.7 | 1.43 | .2816 |
| COMPOSITE ERROR TERM | 236 | -- | 17719.8 | -- | -- |

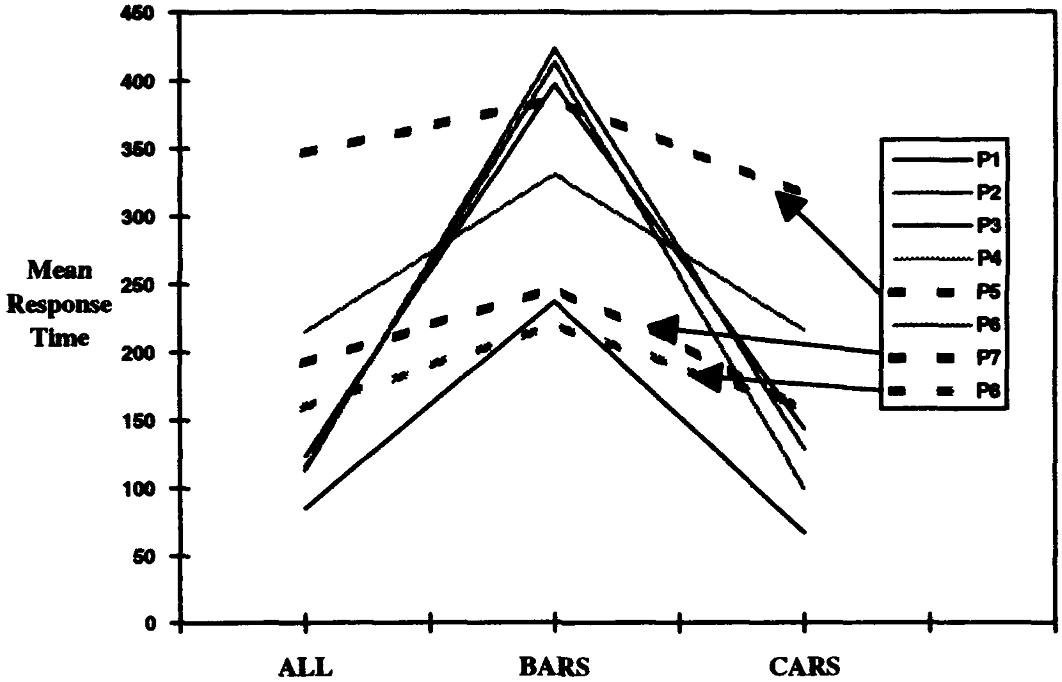



**Figure 4.13 Interaction Plot of Animation and Problem ( Both Presentation Speeds )**

**Multiple Comparisons of Main Effects.** All three main effects ( speed of presentation, type of animation, type of problem) were significant. Comparisons among the levels of each factor reveal the nature of these differences. For factors with multiple levels, the comparisons were made with the Tukey Honestly Significant Difference (HSD) Test using a family $\alpha$ of .05.

Speed of presentation significantly affected the mean response time. The mean response time for problem identification was significantly longer when the animation displayed problems at the faster of the two speeds. Since response time was measured in simulation time units, this indicated that more animated output was required at the faster presentation speed before subjects were ready to identify a problem.

Type of animation had a significant effect on mean response time for problems one through four and problem six. Problems five, seven, and eight did not have significant

differences in mean response time between the different types of animation because bar graphs displayed these problems as well as the car icons did. For the other problems, the Tukey test separated animations into three groups. Animations with the longest mean response times were ones which had the bar graph display. Animations with the combined bar graph and car icon display had the next longest mean response. The shortest mean response was for animations with car icons only.

Type of problem was the final factor with a significant effect on mean response time. Using Tukey's HSD, problems were ordered into the overlapping groups shown in Table 4.5. Each problem is identified by type and description. Problems with the same letter code had mean response times which were not significantly different. Problem five's mean response time was significantly longer than all other problems indicating that it was the most difficult problem to see. Problems four, two, one, and six had mean response times that were significantly different from problem three, indicating that they were more difficult to see than problem three. There were no statistically significant differences between the remaining problems at a family $\alpha$ of .05.

## Subjective Results

Subjective results included the normalized mean rankings of all six animated presentations. Subjects ranked each combination of presentation against every other animated presentation. These pairwise comparisons were transformed into normalized rankings using the geometric means from each subject's matrix of pairwise comparisons. The consistency of each subject's judgments was also evaluated. Two subject's had judgment matrices which did not meet the consistency criterion. Therefore, data from only 52 of the 54 subjects was used to evaluate subjective preferences.

**Table 4.5 Tukey's HSD for Mean Response Time by Problem**

| PROBLEM # / ( TITLE ) | MEAN RESPONSE TIME | TUKEY'S HSD GROUPING | |
|---|---|---|---|
| 5 ( Constant Arrival ) | 349.5 | A | |
| 4 ( False Start ) | 254.0 | B | |
| 2 ( Car Speeds Differ ) | 221.6 | B | |
| 1 ( Cars Pause ) | 221.2 | B | |
| 6 ( Exit Queue ) | 209.0 | B | |
| 7 ( Long Avg. Queue ) | 198.3 | B | C |
| 8 ( Two-way Traffic ) | 179.2 | B | C |
| 3 ( Encroachment ) | 129.5 | | C |

**Summary Statistics.** Overall preferences for each animated presentation were fairly consistent between subjects. Table 4.6 shows the number of subjects who identified each animated presentation as either the "best" or the "worst" presentation they viewed. The combined animation of car icons and bar graphs at the slower speed was selected by 35 subjects (67%) as "best". The presentation of bar graphs at the faster speed was ranked "worst" by 45 subjects (87%).

**Table 4.6 "Best" and "Worst" Animated Presentations**

| Rating | Slow Combined | Slow Bar Graphs | Slow Car Icons | Fast Combined | Fast Bar Graphs | Fast Car Icons |
|---|---|---|---|---|---|---|
| Best | 35 | -- | 12 | 1 | -- | 4 |
| Worst | -- | 2 | -- | 4 | 45 | 1 |

Summary statistics for each animated presentation are shown in Figure 4.14. The mean and standard deviation are shown. There was significantly less variation between subjects for ratings of bar graph displays.

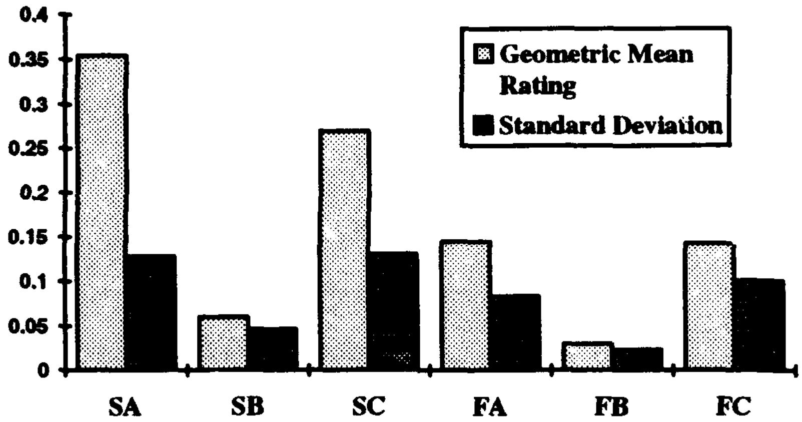



**Figure 4.14 Geometric Means by Animated Presentation**

**ANOVA for Subjective Ratings.** This Analysis of Variance assumed a two-factor repeated measures design. The factors were presentation speed and animation type. Both factors were seen by all subjects and are therefore repeated factors.

**Model Validation.** The significance of the ANOVA results depend on the validity of the model. This repeated measures model assumes that interactions between each of the repeated factors and the random subject factor are possible. Error terms are composed of interactions of each factor with the subject factor. Like completely randomized designs, the error terms are assumed to be normal, independent, and homogeneous within treatments.

First, the assumption of interaction between subjects and the repeated factors was checked with a test on the within-subject error terms. The null hypothesis of homogeneity

for the three within-subject error terms was checked with a Bartlett's test. The results are shown in Table 10. Winer et al recommend setting the type 1 error level at .20 to increase the power of the test. The null hypothesis is rejected (p-value = .06), indicating that the assumption of interactions with subjects is tenable and interactions should not be pooled. As a result, the interaction terms are retained in the model.

**Table 4.7 Homogeneity Test for Interactions with Subjects**

| Homogeneity Test | DF | Test Statistic | Critical Value | P- Value |
|---|---|---|---|---|
| Bartlett's Test | 2 | 5.634 | 4.6 | .06 |

The next model assumption was homogeneity of within-subject treatment variances. All three within-subject treatment variances were evaluated with $F_{max}$ tests. The results of the within-subject homogeneity tests for speed of presentation, type of animation, and the interaction between speed and animation are shown in Table 4.8. In each test, the null hypothesis of variance homogeneity is rejected. The lack of constant within-subject treatment variance invalidates the mode! as currently formulated.

**Table 4.8 Within-Subject Homogeneity Tests**

| Treatment Variance | DF | Test Statistic | Critical Value | P- Value |
|---|---|---|---|---|
| SPEED | 2 , 156 | 2.60 | 1.45 | < .01 |
| ANIMATION | 3 , 104 | 18.233 | 1.50 | < .01 |
| SPEED x ANIMATION | 6 , 52 | 3.406 | 2.20 | < .01 |

Winer and others recommend a transformation on the dependent variable to remedy the heterogeneity problem (Winer and others, 1991:551). A logarithmic transformation was applied to the dependent variable to stabilize the variances. The results of the homogeneity tests after the transformation are shown in Table 4.9. Type of animation is now the only treatment with heterogeneous within-subject variance. The information from each animation level must be used to determine if there are differences in treatment means for this heterogeneous factor (Winer and others, 1991: 527).

**Table 4.9 Within-Subject Homogeneity Tests**
**( Transformed Mean Ratings )**

| Treatment Variance | DF | Test Statistic | Critical Value | P- Value |
|---|---|---|---|---|
| SPEED | 2 , 156 | 1.35 | 1.45 | > .05 |
| ANIMATION | 3 , 104 | 1.71 | 1.49 | < .01 |
| SPEED x ANIMATION | 6 , 52 | 1.94 | 2.20 | > .05 |

As before, the covariance matrices for the repeated factors are assumed to be hetergeneous. The degrees of freedom for the overall F-test were adjusted to assure the validity of the F statistic. For the two-factor within-subjects analysis of variance model, the corrected degrees of freedom were one and n - 1 where n equals the number of subjects. The resulting overall F-tests were negatively biased because the true level of significance was less than the nominal p-value (Keppel, 1991: 465).

**Overall F-Tests.** The resulting ANOVA table is shown in Table 4.10. Degrees of freedom for the computation of mean sums of squares are shown in the table. Degrees of freedom for all tests are one for the numerator and fifty-one for the

denominator. Significant factors include speed of presentation, type of animation, and the two-way interaction of animation with speed of presentation.

**Table 4.10 ANOVA Summary for Subjective Ratings**

| SOURCE | DF | SS | MS | F | P-VALUE |
|---|---|---|---|---|---|
| SPEED | 1 | 47.6964 | 47.6964 | 117.1 | .0000 |
| ANIMATION | 2 | 179.6715 | 89.8357 | 151.4 | .0000 |
| SPEED x ANIMATION | 2 | 1.6750 | .83750 | 4.50 | .0388 |
| SUBJECTS | 51 | 3.8688 | .075859 | -- | -- |
| SPEED x SUBJECTS | 51 | 20.7710 | .40727 | -- | -- |
| ANIMATION x SUBJECTS | 102 | 60.5225 | .593358 | -- | -- |
| SPEED x ANIMATION x SUBJECTS | 102 | 18.9944 | .186220 | -- | -- |

**Simple Effects F-Tests.** The interaction between speed of presentation and type of animation was analyzed by calculating mean sum of square values for the effect of speed at each level of animation. The denominator of each F ratio was a composite error term formed from mean square errors for the interaction and the main effect of speed. Simple main effects of animation at each level of problem are shown in Table 4.11. The null hypothesis is no effect for speed at each level of animation. The simple main effect for speed of presentation was significant for all animated displays. Figure 4.15 shows the interaction effect between these factors. Preference for the combined car icon/bar graph animation over the car icon animation disappears at the faster presentation speed.

**Table 4.11 Simple Effects of Presentation Speed at Each Level of Animation**

| SOURCE | DF | SS | MS | F | P-VALUE |
|---|---|---|---|---|---|
| SPEED at ANIMATION A | 1 | 25.3544 | 25.3544 | 97.55 | .0000 |
| SPEED at ANIMATION B | 1 | 11.195 | 11.195 | 43.07 | .0000 |
| SPEED at ANIMATION C | 1 | 12.8217 | 12.8217 | 49.33 | .0000 |
| COMPOSITE ERROR TERM | 131 | -- | .25991 | -- | -- |

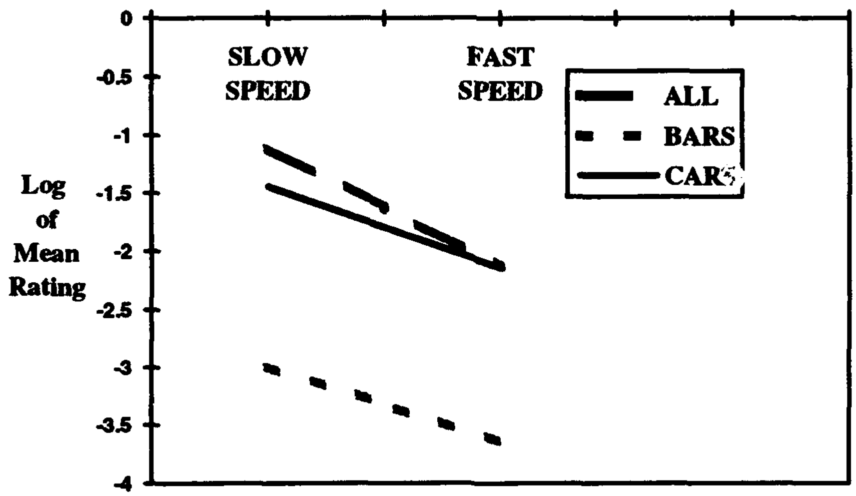



**Figure 4.15 Interaction Plot of Speed and Animation Type**

**Multiple Comparisons of Main Effects.** Both main effects were significant. Comparisons among the levels of each factor reveal the nature of these differences. For differences in the rankings by type of animation, individual comparisons were made using the sample information for each treatment with $\alpha = .01$.

Speed of presentation significantly affected the log of the mean rankings of each animated presentation. These rankings were higher for all animated presentations at the slower of the two speeds. Type of animation also had a significant effect on the log of the mean rankings for each animated presentation. Animations with the combined car icon and bar graph display had the highest rankings. Animations with the car icon display had the next highest rank response. The smallest ranking was for animations with bar graphs.

## Summary of Results

**Objective Results.** These results include problem identification accuracy and the analysis of response time for problem identification. Problem identification accuracy was similar at both presentation speeds for all problems except problem four. Identification accuracy for problem four was significantly lower at the faster presentation speed. Problems one and two were not identified in animated presentations with bar graphs only. Problem five was not identified in animated presentations with car icons only. Identification accuracy using animations with car icons was greater for all problems except problem five.

The ANOVA model for problem response time identified several significant factors. All main effects (speed of presentation, type of animation, type of problem) were significant. The interaction of animation and problem types was also significant. Response times were significantly longer at the faster presentation speed. For problems one, two, three, four, and six, response time was longest for bar graph animations. These problems also had longer response times for the combined animation than for the car icon

animation. Problems five, seven, and eight had similar response times for each animated presentation. Problem five had a significantly longer response time than the other problems while problem three's response was significantly shorter.

**Subjective Results.** Two-thirds of the subjects rated the slower presentation of car icons and bar graphs as the "best" animation. One-fourth of the subjects rated the slower presentation of car icons as "best". The vast majority of subjects (87%) felt that the faster presentation of bar graphs was the "worst" animation they saw.

The ANOVA model for subjective rankings of animated presentations identified each of the factors as significant. The interaction between speed of presentation and type of animation resulted in preference for the combined animation over the car icon display at the slower presentation speed only. Preferences for each of the animated presentations were significantly higher at the slower presentation speed. Preference was highest for the combined animation, followed by the car icon display, and then the bar graph display.

# V. Discussion

The previous chapter quantified the statistical relationships between presentation speed, animation type, and subjects' ability to identify problems in an accurate, timely manner. This chapter addresses the significant relationships to explain why particular animation factors were effective. The discussion begins with a summary of significant comments from subjects who participated in the research. Next, the discussion relates the subjects' comments to their subjective ratings of the animations. Then, the objective results are examined to explain reasons for the influence of each significant factor. Finally, the subjective results are compared with the objective results.

## Subjects' Comments

Most comments were opinions on the preferred presentation speed for each animation display. The majority of respondents felt that the slower speed of presentation was fast enough to challenge their ability to detect problems in the underlying simulation. This opinion was particularly strong for the combined and bar graph animations. Most subjects felt that the screen elements were changing too quickly with the fast presentation of car icons and bar graphs. Many of them said they adjusted t[illegible]erload of information by ignoring the bar graph portion of the animation. Subjects complained about the fast presentation of bar graphs most. They felt that the changes in bar levels happened too fast for them to detect the underlying problems.

Comments about each animated presentation revealed common preferences. Displays with car icons were perceived as a natural depiction of the problem. Bar graph displays were viewed as an abstract presentation which was harder to understand. Some subjects tried to picture how a violation of certain model assumptions would look in the

bar graph display and often struggled doing so. Most subjects said they focused on the car icons when viewing the combined animation at either speed. Some subjects tried to incorporate the bar graphs in their visual scan, while others stated that they completely ignored the "bars". Many subjects felt that the interarrival bar graphs were useful, but most disliked the way the other bar graphs depicted traffic flow.

Subjects also commented on the difficulty of detecting violations of each model assumption. Most felt that the model assumptions were hard to remember as they viewed each problem scenario for potential violations. Some described a hierarchy of problems they looked for, starting with the ones they considered easier to detect and finishing with problems that either required time to develop or ones which they considered difficult to see. Many subjects focused their attention on traffic movement on or near the bridge and only redirected their gaze if unusual behavior in another part of the screen "caught their eye". For these subjects and many others, problems with a more subtle presentation often escaped notice.

## Subjective Results

The opinions which subjects' expressed were reflected in their subjective ratings. Two-thirds of the subjects rated the combined animation at the slower speed as "best" because they felt that more information was better even if they didn't actually use it in their problem search. The fast presentation of bar graphs was rated worst by nearly every subject because they felt the faster speed made an abstract presentation even more difficult to understand.

Pairwise ratings for animation and speed factors were consistent with comments expressed by the majority of subjects. Slower speed animations were preferred because they gave subjects more time to think. Subjects appreciated time to think about what they had just seen before something new appeared on the screen. The combined

animation was preferred at the slower speed only because most subjects felt they could only look at the car icons during the faster presentation. At the faster speed, they felt any animation with car icons was equally valuable. This suggests that viewers of more complex animations may prefer slower presentation speeds to allow time to incorporate information from multiple elements.

Subjects clearly preferred animations with car icons to those with bar graphs alone. They felt more comfortable with the bird's-eye view of the traffic flow than they did with the abstract bar graph representation. The affinity between subjects and the pictorial car icon display made this presentation easy to use. The bar graph display was much more challenging. Subjects asked a number of questions about this display as they tried to understand how changing bar levels represented information on traffic flow.

## Objective Results

Subjective opinions provided one tool for the evaluation of each animation. Objective results were also obtained to judge the communicative power of each animation. The objective results included problem identification accuracy as well as problem response times. These two measures offer additional perspectives on the relative value of each of the display factors examined in this research.

**Problem Identification Accuracy.** This measure was a record of the percentage of correct identifications for each type of problem under each combination of animation type and presentation speed. In general, identification accuracy was similar across most combinations of presentation speed and type of animation. There were a few notable differences. These differences highlight the impact that animated presentations have on identification of particular problems in a simulation validation effort.

**Problems Masked by Animations.** Two problems were masked under bar graph animations. Problem one had cars which paused at the bridge when the light

was green. Problem two had cars which traveled twice as fast in one direction as they did in the other direction. Neither of these problems was accurately identified by the 18 subjects who viewed the problems with bar graph animations. In the first problem, the stop-and-go nature of the cars was imperceptible in the longer duration that the car was displayed on the "inbound" bar graph. For problem two, the faster rate of change in bar graph levels for the faster cars was not noticeable. In both cases, the bar graph animations disguised the problem and made it unrecognizable.

Another problem was masked when viewed in car icon animations. Problem five involved a constant arrival of eastbound cars, violating the assumption of a random traffic flow. This problem was difficult to see in any animated presentation, but it was not detected at all in car icon animations. Bar graph animations displayed a constant bar height for interarrival time. Subjects noticed the unchanging bar height and identified the problem with bar graph animations, but failed to detect the problem with car icon animations. The car icon animations disguised the problem and made it unrecognizable.

**Display of Integrated Information.** An emergent feature is a meaningful pattern revealed in the combination of simple display elements which is not present in any single or smaller group of elements (Sanderson et al., 1989:192). Displays with prominent emergent features are more effective for information integration tasks. In this experiment, information on individual entities (cars) was integrated with the traffic light display to detect problems in traffic flow. For the bar graph animations, the nonstandard flow of traffic was revealed in unusual patterns in the levels of bars. It was hypothesized that these patterns (emergent features) would make the bar graph displays effective for traffic flow problems involving many cars.

There were two problems which displayed abnormal traffic flow. Problem five had constant interarrival times. Since this problem was revealed in the level of a single bar element, the display does not present an emergent feature. Problem seven had an

imbalance in the eastbound and westbound queue lengths, indicating that light timing did not compensate for the differences in traffic volume. For problem seven, the emergent feature was an imbalance between the levels of the bars representing traffic on each inbound roadway. Therefore, problem seven was an information integration task in which the bar graph display had an emergent feature.

Problem identification accuracy for problem seven, however, was superior for animations which included car icons. The emergent feature for the bar graph display was less effective because the displayed pattern was not meaningful. The car icon display was more effective in this information integration task because its car elements more directly represented the imbalance in average queue lengths. The car icon display was also effective because its separate elements were effectively grouped.

The close grouping and common color of individual cars made this iconic display "proximally compatible". Andre and Wickens have shown that information integration tasks benefit from "proximally compatible" displays where *elements requiring integration* are color coded and closely grouped (Andre and Wickens, 1990:65). The inbound car icons resembled a horizontal bar graph. The direct representation of unequal lines of cars made the icon display a better indication of this problem. In this example, an effectively grouped icon display was superior to an abstract bar graph display in integrating information on traffic flow.

**Effect of Presentation Speed.** Accuracy of problem identifications was comparable across all problems except problem four. Problem four had the first car move onto the bridge before the traffic signal turned green. This discrete change was observable if the subject noticed that the car movement occurred before the light had changed. Although, the car moved onto the bridge a full two seconds (simulated time) before the light changed, this discrete change was much less observable at the faster presentation speed. The difference between discrete events was one-half second (real time) at the

slower presentation speed, but only one-quarter second for the faster presentation speed. The difference in problem identification indicates that the detection of some invalid events is sensitive to the speed at which they are presented.

**Problem Response Times.** Problem accuracy data indicated if problems were correctly identified. Problem response time measured how much simulation output was viewed before subjects were ready to identify a problem. Response times were measured in simulation time units to provide a common scale under each of the two presentation speeds. A longer response time therefore indicated that more animation events were viewed before a subject was ready to identify a problem. The analysis of variance model for response time identified three significant factors and one significant two-way interaction. First, the interaction is addressed. Then, the factor effects are discussed.

**Interaction of Problem and Animation Type.** Response time was influenced by the interaction between animation displays and problem types. For problems one, two, three, four, and six, mean response times were *significantly different for each* type of animation. For these problems, the car icon animation had the shortest response time, the combined animation was next, and the bar graph animation had the longest response time. For the other problems, however, mean response time was not significantly different for any of the animations. Problems five, seven, and eight had similar response times under all animations.

Car icon displays were more effective for problems involving one or a few car entities. Each of these problems required subjects to detect improper relationships among a few cars or between the movement of car(s) and the status of the traffic light. Task performance for these simpler information integration problems was generally superior for the car icon display. The bar graph displays were less effective because their abstract display made the behavior of individual entities more difficult to see and interpret.

The effects of animation were not significant for problems five, seven, and eight. The first two problems required information integration on traffic flow. Problem five involved the constant arrival of all eastbound cars and was displayed with a constant interarrival bar level. Problem seven was the unbalanced queue length scenario in which average queue lengths were too large for westbound cars. Response times for these more complex information integration tasks were similar for all animations. For problem seven, the emergent feature in the bar graph display was more effective for response time than it was for problem identification. For problem eight, the simultaneous presence of "mid" bars indicated that there was two-way traffic on the bridge. The bar graph display was effective because the "mid" bars were color coded and therefore easier to compare. In all three cases, problems were highlighted equally fast with either type of animation.

**Effect of Presentation Speed.** Mean response time was also influenced by the speed at which each animation was shown. Responses were significantly faster at the slower presentation speed. Most subjects felt that the slower rate of change in animated events made the relationships more apparent. At the faster speed, problems were more difficult to see because there were more animated events to view each second. Table 5.1 shows the average number of discrete animated events displayed per second for each problem. Discrete animated events include light changes, car arrivals, car departures, and car transitions from one roadway segment to the next. Although the discrete animated events per second appear large, the majority of animated events represented valid traffic movement. The faster presentation speed made greater perceptual and information-processing demands on each subject. As a result, many subjects required more repetitions of each problem before they noticed the problem and were confident that the observed behavior was abnormal.

**Effect of Problem Type.** The type of problem also had a significant influence on response time. Problems varied in several ways. First, some

problems attracted attention because they were displayed with dynamic movement. The second difference between problems was the degree of repetition. All problems were programmed to be repetitive, to allow each subject to have several opportunities to observe the same problem. Some problems repeated at more frequent intervals which gave subjects more opportunities to observe them. These two characteristics help explain the differences in response times for each group of problems.

**Table 5.1 Discrete Animated Events Displayed Per Second**

| PROBLEM # / ( TITLE ) | # of Discrete Animated Events (DAE) | Average DAE / second (Slower Speed) | Average DAE / second (Faster Speed) |
|---|---|---|---|
| 1 ( Cars Pause ) | 432 | 3.6 | 7.2 |
| 2 ( Car Speeds Differ ) | 432 | 3.6 | 7.2 |
| 3 ( Encroachment ) | 468 | 3.9 | 7.8 |
| 4 ( False Start ) | 432 | 3.6 | 7.2 |
| 5 ( Constant Arrival ) | 432 | 3.6 | 7.2 |
| 6 ( Exit Queue ) | 360 | 3.0 | 6.0 |
| 7 ( Long Avg. Queue ) | 452 | 3.8 | 7.6 |
| 8 ( Two-way Traffic ) | 636 | 5.8 | 10.6 |
| Average for All Problems | 456 | 3.8 | 7.6 |

Problem five had a significantly longer response time than any other problem. This problem lagged in response time because it was not displayed with dynamic movement. The problem involved the constant arrival of eastbound cars. Although this problem was repeated with every arrival, the steady stream of arriving cars was a subtle

symptom of a model violation. The constant level for the interarrival bar graph was the only display that subjects were able to use. This indication was so subtle that most subjects had difficulty recognizing the constant arrival of eastbound cars.

Four of the remaining problems ( four, two, one, and six) had mean response times that were longer than problem three. Problem four's mean response time was significantly greater because the problem indications were subtle and infrequent. Both problems one and two had longer mean response times because these problems lacked dynamic movement in the bar graph animations. Problem six also lacked dynamic movement and had fewer repetitions. In each case, the lack of dynamic problem indications or repetition increased the required response time.

The final group of problems with similar mean response times included problems seven, eight, and three. The first two problems had dynamic indications in either of the animated displays. The primary reason for the shorter mean response time for problem three was its highly repetitive nature. Problem three displayed inadequate interarrival spacing for every third car arriving from either direction. The animated indication of this problem was also dynamic making this problem's response time shortest of all.

## Comparison of Objective and Subjective Results

Both types of results were based on the common factors of animation type and presentation speed. Subjects did not subjectively evaluate problem types so no comparisons can be made for this factor. Each subject completed the objective portion of the experiment before the subjective part. The results from each part of the experiment are consistent with some minor differences.

Subjects felt that slower speed animations communicated model behavior more clearly. Objective results for response time agree with significantly lower mean response

times for slower speed animations. Identification accuracy at the slower speed, however, was not significantly different from accuracy at the faster speed.

Subjects also rated the slower speed presentation of the combined car icon and bar graph animation superior to slower speed animations with car icons only. Objective results do not support this judgment. Mean response time results are similar for all animations with car icons. Identification accuracy results are also similar for all animations with car icons. The difference between the subjective and objective results here indicates that subjects preferred redundant display information, but their overall performance with this extra information did not improve. Carpenter found a similar difference between subjective preference and objective performance in his animation research (Carpenter, 1993:57).

Subjects had no preference between animations with car icons at the faster presentation speed. Objective results support the subjective assessment here. Mean response times for both animations with car icons were not significantly different at the faster presentation speed. Identification accuracy results for both animations with car icons were also similar at the faster presentation speed.

Finally, there was consistent agreement between subjective and objective results for comparisons between animations with car icons and animations with bar graphs only. Subjects preferred animations with car icons to those with bar graphs. Response times for car icon animations supported the subjective preference. For most problems, responses were significantly faster for car icon animations. Identification accuracy for animations with car icons was generally as good or better than that for bar graph animations.

# VI. Conclusions and Recommendations

## Conclusions

**Summary.** Animation is gaining increasing acceptance as a display and communication tool that supports the validity of computer simulation models. Carson recommends animation as a tool for establishing face validity and for validating model assumptions (Carson, 1989: 555). In this study, animation was used to determine if a simulation model operated in accordance with its assumptions. Each subject viewed one of six combinations of presentation speed and animation type. Eight problem scenarios were presented, each one depicting the violation of a model assumption. Subjects viewed each scenario and identified violations as soon as they observed them. Objective measures included problem identification accuracy and response times. After viewing the problem scenarios, each subject viewed a valid simulation model under all six combinations of presentation speed and animation type. Subjects then made pairwise comparisons to indicate subjective preferences between each of the animated presentations.

**Results.** The objective results indicated that the slower presentation speed was superior to the faster speed and that animations with icons were superior to animations with bar graphs. A slower presentation speed resulted in significantly shorter response times with the same or better problem identification accuracy. For problems involving the movement of a few entities, animations with icons had significantly shorter response times with the same or better identification accuracy. For problems involving information integration, bar graph displays had response times which were similar to those of the iconic displays. Presentation speed significantly affected the identification accuracy of one problem. Animation type also had a significant effect on identification accuracy for three of the eight problems.

Subjects preferred the slower speed of presentation and animations with icon displays. The most preferred animated presentation, however, was the one with both bar graphs and car icons at the slower speed. At the faster speed, there was no difference in subjective preference between either of the animations with car icons. The least preferred animation was the bar graph presentation at the faster presentation speed.

**Limitations.** The sample population consisted of faculty and graduate students from the engineering school at the Air Force Institute of Technology. No prior experience with simulation or animation was required for participation in this experiment. This sample is representative of technically-educated lower to mid-level Air Force managers. However, since the subjects of this research are a convenience sample, the results may not be totally applicable to the general population of simulation and animation users (Keppel, 1991:17-18).

Subjects received a brief instructional presentation and two demonstrations of a sample animation. The pre-training period described the model and answered all questions, but it did not transform the subjects into system experts. Variability in the results due to subjects incomplete understanding of the model or its assumptions might have been further reduced with more extensive training. A simple model from everyday experience was chosen to reduce the required training, but some confusion may have remained.

Finally, the results of this study are applicable to the fixed factor levels included in the research. The speeds of presentation, animations , and problems were fixed by the requirement to display a cross section of violations for this model's assumptions. The applicability of this research is limited by the fact that presentation speeds, animation displays, and relevant problems were specific to the model at hand and likely to change for any other model.

**Additional Observations.** The pitfall in an experiment of this nature is to have the subjects see the problems you want them to see and no others. During early screening trials, subjects identified unintended problems which were then eliminated from the animation. This process emphasized the value of animation as a modeler's debugging tool because several problems were identified from these early animations.

Problem identifications were poor for some problem scenarios. One of the significant causes for incorrect identifications was a rush to judgment from some subjects. Law and Kelton argue that animation is no substitute for a careful statistical analysis of model output. They feel that watching an animation for a short period of time may give an erroneous impression of long term model behavior (Law and Kelton, 1991:242). Several subjects overreacted to random variability in the simulation output and concluded that average queue lengths were not equal. In every case, the conclusion was not justified based on the short sample of animated output they had seen. This problem emphasized the need to judge long term model behavior with appropriate sample statistics.

Law and Kelton also state that animation can show that an animation is **not** valid, but it cannot show that an animation is valid (Law and Kelton, 1991:242). This animation supported Law and Kelton's view because some problems were not visible in certain animated displays. Other problems were visible, but difficult to notice because the subjects were not specifically looking for them. The results of this research indicate that animation results may support validity assessments, but they do not prove a model is valid.

## Recommendations

**Guidelines for Effective Animation.** Viewing an animation to discover invalid operation is a complicated task. The viewer must understand the display elements, the relationships between these elements, and how violations of model assumptions will appear if/when they occur. The results of this study, similar animation research

(Carpenter, 1993), and the animation literature offer the following six practical guidelines for creating effective animation presentations.

**1) Use pictorial displays with moving icons when animating simulation models with moving entities.** Pictorial displays provide a concrete, intuitive representation of the model. Moving icons have proven to be useful for models involving the interaction of moving entities (Carson and Atala, 1990:798-801; Carpenter, 1993:57; Zhao and Pirasteh, 1992:409).

**2) Design the display with the validation tasks in mind.** If you want to focus attention on display elements, keep these elements separate from other competing elements. If you want to integrate the information from separate elements, relate these elements by grouping them close together, within closed contours, or with a common color code. In this study, interarrival bars were separated to distinguish their information from that of the other bar graphs. The other bar graphs were grouped to integrate their information.

**3) Indicate problems with dynamic contrasts.** Problems with a subtle indication may be lost in the other animated activity. Indications with dynamic contrasts in shape, pattern, color, etc. are more noticeable. In this research, problems indicated with subtle contrasts were significantly more difficult to notice.

**4) Set/adjust the presentation speed to make discrete differences visible.** Differences between significant discrete animated events should be visible in the animation. In this research, discrete differences of one-quarter second where significantly more difficult to notice than differences of one-half second.

**5) Avoid overloading the user with too much visual information.** A large number of discrete animated changes can overload the user. This overload can occur if a complicated animation is shown at a fast speed. If the user cannot comfortably scan the entire animation, he may view a small portion of the screen and miss important information. Subjects in this research ignored the bar graph display when they felt overloaded and missed the interarrival information that bar graphs displayed best.

**6) Train the user to effectively scan the animation for potential problems.** Users will validate the model more effectively if they understand the animation display elements, the relationship between elements, and how potential problems are indicated in the animated output. This training will also prevent users from overreacting to normal animated behavior which they do not understand.

**Recommendations for Further Research.** This research examined how effectively each of three types of animations displayed violations of model assumptions at each of two presentation speeds. In light of the results and limitations of this research, the following studies are recommended:

**1) Investigate the nature of the relationship between viewing speed and the communicative power of an animation display.** Are discrete animated events per second a useful measure of animation speed or does a more meaningful measure exist? The subjects in this study preferred the slower of the two speeds. Are slower speeds always preferable? Is there a speed that subjects would judge as too slow? How does performance vary across a range of viewing speeds?

**2) Examine the use of bar graphs in a more challenging integration task.** For this research, bar graphs integrated information on only 12 cars at a time. Larger levels of entities might make bar graphs a better alternative display. What are the information integration tasks better suited to a bar graph representation? For what level of entities (if any) are bar graphs a more effective display versus the display of individual icons?

**3) Repeat this research with a more complex real world system.** This research might also require real "system experts" to judge each animation presentation's ability to display violations of model assumptions. One interesting option might be an inventory system where items are stored and moved individually and in groups of varying size.

**4) Investigate the use of other animation elements such as color changes or sound to indicate that a model's operational limits are being approached.** These indicator elements would serve as attention-getters to focus the viewer's attention on a potential problem area. These elements could be used with icons or other display elements to improve the communication potential of the animation.

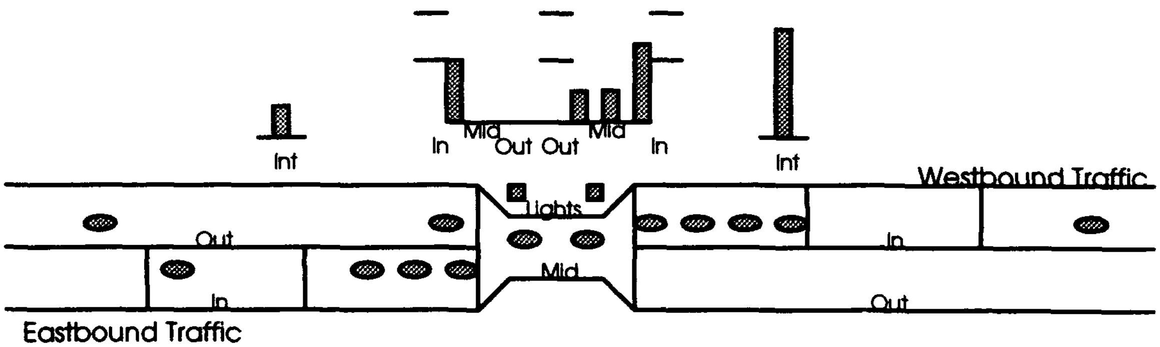
## Appendix A. Experimental Forms

This appendix shows the experimental forms used to run the animation experiment and collect experimental data. Pages A-2 through A-4 show the model description and experimental instructions which each subject received. Page A-5 is the form used to record each subject's response times. Pages A-6, A-7 show the instruction each subject received on the pairwise comparison procedure. Page A-8 is the form used to collect each subject's pairwise comparisons and the final page is an example of a completed form for the pairwise comparison judgment matrix.

## A Traffic Analysis Model

The traffic situation in this model involves two-way traffic sharing a one-lane bridge. A traffic signal prevents two-way traffic on the bridge. A traffic engineer has created a simulation to model the system using the following assumptions:

1) All cars travel at the same speeds.
2) All cars are the same size/shape.
3) All cars maintain physical separation with the car ahead of them.
4) Arrival times for cars from both direction are random variables.
5) All cars stop at red lights and proceed when the light is green.
6) Traffic signals allow time for cars to clear the bridge before cars from the opposite direction are allowed to proceed.
7) Traffic signals are timed to make the average queue lengths approximately equal for both directions of travel.




Traffic Analysis Model

### ROADWAY DISPLAY

The first segment labeled "In" is the roadway from the entry point to the bridge. This is the area where cars queue up when the light is red. (Reference lines are 4 cars apart).

The second segment labeled "Mid" is the bridge. Traffic on the bridge is one-way.

The final segment labeled "Out" is the roadway from the bridge to the exit point.

### BAR GRAPH DISPLAY

The number of cars in each roadway segment ("In", "Mid", "Out") is shown by its respective bar graph. Each bar increases when a car enters the segment and decreases when a car exits the segment. A missing bar indicates no cars in the roadway segment. (Reference lines are also at four-car intervals).

Interarrival times between cars are shown with the bar graphs labeled "INT". The level of these bars changes to indicate each interarrival time. A missing bar indicates an interarrival time too small to provide physical separation between cars.

The Experiment

The traffic engineer explains her model to you. As her supervisor, you view the animation to see if it faithfully represents the model as described. You will view eight unique traffic scenarios.

Each traffic scenario is completely independent of the other scenarios. The amount of traffic, speeds of travel, light timing, etc. may be different from one scenario to the next. These differences represent different traffic conditions.

As you view each of the following animated presentations, **RAISE YOUR HAND** or **say "STOP"** as soon as you can confidently identify where a model assumption has been violated. Violations of assumptions show up repeatedly in each scenario. Some violations are difficult to see in certain animation displays. You will view each scenario for a maximum of one minute ( two minutes for slower animation speeds). Be prepared to identify any problems you observe.

The animation displays and speeds of presentation are not the same for everyone who

participates in this experiment. You will view your experimental trials at the ______

speed. Your animation display is ____________.

I will be recording your response time and your problem identification. Accuracy of problem identification is just as important as a timely response.

Now, I will show you an animation of a simulation which observes all the stated traffic model assumptions. First, I will review the various display elements. Then, I will show you the sample animation. After a review of model assumptions, I will then show you the sample animation a second time. Feel free to ask questions at any time during the demonstration.

Narration for Sample Animation

Description of Animation Elements:

Cars travel from one side of the screen to the other on a roadway that has three segments.

The first segment labeled "In" is the roadway from the entry point to the bridge.

The second segment labeled "Mid" is the bridge. Traffic on the bridge is one-way.

The final segment labeled "Out" is the roadway from the bridge to the exit point.

Each of the three bar graphs for each direction show the number of cars in that road segment at any time. These bars are missing if there are no cars on the road segment.

The "In" bars show the number of cars on either inbound road segment..

The "Mid" bars show the number of cars from either direction on the bridge.

The "Out" bars show the number of cars on the outbound roadway segment.

The "Int" bars show the difference between the arrival time of one car and the next car. This bar is shown when the difference is large enough to provide separation between cars.

Now, I will show you a brief demonstration of these animation elements in action.

Do you have any questions about animation elements you have just seen ?

Please take a moment to review the model assumptions. (PAUSE)

As you view the sample animation a second time, try to picture how violations of each model assumption would look if they were present.

Please feel free to ask any questions you might have before we start the experiment.

Subject Animation Problem Data

Name: _______________ Date: __________ Run: __________

Animation/Speed: SALL FALL SBAR FBAR SCAR FCAR
( Circle One )

| Problem Scenario | Problem Identification | I.D. Time |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |

Pairwise Comparisons

The six animated presentations you have just seen communicate the operation of the underlying simulation of the traffic model. These presentations differ in their pictorial elements and the speed of their presentation. The following comparisons allow you to rate the communication ability of each presentation against every other presentation. Since there are six presentations, you will make 15 pairwise comparisons .

After you have completed the first few comparisons, I will review one or two responses with you to verify our common understanding of the pairwise rating procedure. Feel free to go back and change a previous response any time your opinion changes. The order of your responses is not important. Please complete the entire form with your honest comparisons of the various animated presentations.

As a reminder, the presentations for comparison are:

- SALL - The slower presentation of both car icons and bar graphs.
- FALL - The faster presentation of both car icons and bar graphs.
- SCARS - The slower presentation of car icons only.
- FCARS - The faster presentation of car icons only.
- SBARS - The slower presentation of bar graphs only.
- FBARS - The faster presentation of bar graphs only.

The next page presents several example comparisons between two hypothetical animated presentations. In each case, the rater has indicated the relative preference between the two presentations by marking the box closest to the preferred alternative.

The third page is the form you fill out to indicate your pairwise comparisons.

Example Pairwise Comparisons of Animated Presentations

"Presentation **A** and Presentation **B** are *equally good* at communicating model behavior."

| | >>>> | >>> | >> | > | = | < | << | <<< | <<<< | |
|---|---|---|---|---|---|---|---|---|---|---|
| A | _ _ | _ _ | _ _ | _ _ | X | _ _ | _ _ | _ _ | _ _ | B |

"Presentation **A** communicates model behavior *a great deal better* than Presentation **B**."

| | >>>> | >>> | >> | > | = | < | << | <<< | <<<< | |
|---|---|---|---|---|---|---|---|---|---|---|
| A | X _ | _ _ | _ _ | _ _ | _ | _ _ | _ _ | _ _ | _ _ | B |

"Presentation **A** communicates model behavior *much better* than Presentation **B**."

| | >>>> | >>> | >> | > | = | < | << | <<< | <<<< | |
|---|---|---|---|---|---|---|---|---|---|---|
| A | _ _ | _ X | _ _ | _ _ | _ | _ _ | _ _ | _ _ | _ _ | B |

"Presentation **B** communicates model behavior *better* than Presentation **A**."

| | >>>> | >>> | >> | > | = | < | << | <<< | <<<< | |
|---|---|---|---|---|---|---|---|---|---|---|
| A | _ _ | _ _ | _ _ | _ _ | _ | _ _ | X _ | _ _ | _ _ | B |

"Presentation **B** communicates model behavior *slightly better* than Presentation **A**."

| | >>>> | >>> | >> | > | = | < | << | <<< | <<<< | |
|---|---|---|---|---|---|---|---|---|---|---|
| A | _ _ | _ _ | _ _ | _ _ | _ | X _ | _ _ | _ _ | _ _ | B |

"Presentation **B** communicates model behavior *much better* than Presentation **A**."

| | >>>> | >>> | >> | > | = | < | << | <<< | <<<< | |
|---|---|---|---|---|---|---|---|---|---|---|
| A | _ _ | _ _ | _ _ | _ _ | _ | _ _ | _ _ | X _ | _ _ | B |

## Subject Pairwise Comparison Form

Name: ____________________ Date: ___________ Run: _______

| | >>>> | >>> | >> | > | = | < | << | <<< | <<<< | |
|---|---|---|---|---|---|---|---|---|---|---|
| SALL | | | | | | | | | | SBARS |
| SALL | | | | | | | | | | SCARS |
| SALL | | | | | | | | | | FALL |
| SALL | | | | | | | | | | FBARS |
| SALL | | | | | | | | | | FCARS |
| SCARS | | | | | | | | | | SBARS |
| SCARS | | | | | | | | | | FALL |
| SCARS | | | | | | | | | | FBARS |
| SCARS | | | | | | | | | | FCARS |
| SBARS | | | | | | | | | | FALL |
| SBARS | | | | | | | | | | FBARS |
| SBARS | | | | | | | | | | FCARS |
| FALL | | | | | | | | | | FBARS |
| FALL | | | | | | | | | | FCARS |
| FBARS | | | | | | | | | | FCARS |

Pairwise Matrix

Name: Sample Date: January 1994 Run: # 0

| | SALL | SBARS | SCARS | FALL | FBARS | FCARS | Normalized Geometric Mean Ratings |
|---|---|---|---|---|---|---|---|
| SALL | 1 | 8 | 4 | 4 | 9 | 5 | 0.452 |
| SBARS | 1/8 | 1 | 1/4 | 1/7 | 4 | 1/4 | 0.043 |
| SCARS | 1/4 | 4 | 1 | 1/5 | 6 | 1/2 | 0.098 |
| FALL | 1/4 | 7 | 5 | 1 | 7 | 3 | 0.254 |
| FBARS | 1/9 | 1/4 | 1/6 | 1/7 | 1 | 1/6 | 0.023 |
| FCARS | 1/5 | 4 | 2 | 1/3 | 6 | 1 | 0.129 |

$S^2$ = .361 **Pass** / Fail

## Appendix B. Data Files and SAS Code

This appendix shows the data files and SAS code used in the ANOVA of the objective and subjective experimental data. Cody and Smith provided excellent source code for both of the repeated measures ANOVAs ( Cody and Smith, 1991:163-203). The code in this appendix is adapted from their examples. The data for the objective portion of the experiment is first followed by the SAS code for the three factor repeated measures ANOVA model used in the data analysis. The data for the subjective portion of the experiment is next followed by SAS code for the two factor repeated measures ANOVA used in the data analysis.

TIMES.DAT PROBLEM DATA FOR RESPONSE TIMES

| SUBJ | SPEED | ANIM | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | F | B | 480 | 480 | 235 | 480 | 170 | 480 | 231 | 110 |
| 2 | F | A | 36 | 480 | 41 | 308 | 480 | 53 | 163 | 480 |
| 3 | S | B | 480 | 207 | 81 | 356 | 131 | 480 | 87 | 94 |
| 4 | S | A | 121 | 15 | 16 | 75 | 119 | 55 | 147 | 140 |
| 5 | S | C | 12 | 16 | 55 | 47 | 186 | 39 | 65 | 66 |
| 6 | F | C | 67 | 65 | 78 | 82 | 480 | 153 | 480 | 108 |
| 7 | F | A | 159 | 141 | 36 | 154 | 91 | 47 | 84 | 98 |
| 8 | F | C | 80 | 46 | 324 | 142 | 417 | 135 | 132 | 313 |
| 9 | S | C | 32 | 47 | 24 | 480 | 98 | 40 | 101 | 71 |
| 10 | S | B | 480 | 480 | 480 | 231 | 390 | 480 | 259 | 127 |
| 11 | S | A | 15 | 14 | 16 | 142 | 480 | 26 | 71 | 166 |
| 12 | F | B | 480 | 480 | 89 | 397 | 480 | 480 | 147 | 111 |
| 13 | S | B | 302 | 425 | 366 | 110 | 480 | 480 | 480 | 101 |
| 14 | F | C | 126 | 51 | 96 | 139 | 95 | 26 | 138 | 53 |
| 15 | S | C | 30 | 11 | 15 | 13 | 211 | 101 | 134 | 41 |
| 16 | S | A | 37 | 39 | 24 | 175 | 480 | 32 | 157 | 100 |
| 17 | F | A | 480 | 59 | 212 | 480 | 271 | 474 | 377 | 137 |
| 18 | F | B | 480 | 480 | 299 | 480 | 480 | 480 | 200 | 480 |
| 19 | F | A | 183 | 480 | 88 | 141 | 480 | 144 | 90 | 200 |
| 20 | F | B | 480 | 480 | 480 | 480 | 480 | 391 | 480 | 480 |
| 21 | S | C | 65 | 35 | 17 | 131 | 86 | 57 | 86 | 105 |
| 22 | F | C | 154 | 80 | 89 | 56 | 138 | 93 | 102 | 113 |
| 23 | S | A | 118 | 131 | 30 | 260 | 480 | 92 | 470 | 78 |
| 24 | S | B | 338 | 480 | 146 | 230 | 201 | 140 | 77 | 351 |
| 25 | F | B | 480 | 228 | 479 | 211 | 480 | 480 | 480 | 219 |
| 26 | S | C | 243 | 45 | 65 | 57 | 480 | 207 | 93 | 101 |
| 27 | S | B | 40 | 302 | 132 | 15 | 367 | 101 | 186 | 59 |
| 28 | F | C | 89 | 59 | 118 | 480 | 350 | 43 | 131 | 480 |
| 29 | F | A | 195 | 107 | 63 | 480 | 480 | 209 | 370 | 480 |
| 30 | S | A | 152 | 63 | 67 | 170 | 480 | 31 | 204 | 73 |
| 31 | S | C | 64 | 33 | 25 | 75 | 480 | 100 | 115 | 79 |
| 32 | F | C | 282 | 480 | 34 | 480 | 480 | 262 | 93 | 480 |
| 33 | F | A | 140 | 98 | 92 | 52 | 480 | 52 | 83 | 164 |
| 34 | S | A | 13 | 38 | 63 | 10 | 185 | 209 | 115 | 79 |
| 35 | F | B | 480 | 480 | 378 | 480 | 480 | 480 | 480 | 480 |
| 36 | S | B | 480 | 480 | 14 | 480 | 480 | 480 | 188 | 480 |
| 37 | S | B | 158 | 480 | 135 | 83 | 345 | 480 | 104 | 62 |
| 38 | F | B | 480 | 480 | 99 | 480 | 480 | 480 | 184 | 107 |

| SUBJ | SPEED | ANIM | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 |
|---|---|---|---|---|---|---|---|---|---|---|
| 39 | S | C | 152 | 62 | 27 | 44 | 480 | 111 | 228 | 103 |
| 40 | F | A | 115 | 106 | 139 | 220 | 480 | 160 | 88 | 105 |
| 41 | S | A | 32 | 46 | 16 | 320 | 480 | 33 | 125 | 100 |
| 42 | F | C | 103 | 480 | 48 | 480 | 480 | 48 | 110 | 167 |
| 43 | F | B | 480 | 214 | 480 | 164 | 480 | 480 | 480 | 292 |
| 44 | S | B | 468 | 480 | 295 | 477 | 368 | 480 | 27 | 99 |
| 45 | S | C | 87 | 18 | 15 | 45 | 480 | 80 | 130 | 162 |
| 46 | F | A | 150 | 76 | 76 | 480 | 472 | 167 | 172 | 100 |
| 47 | S | A | 29 | 39 | 34 | 11 | 82 | 97 | 113 | 85 |
| 48 | F | C | 480 | 204 | 107 | 480 | 227 | 155 | 89 | 167 |
| 49 | F | C | 480 | 103 | 34 | 480 | 207 | 48 | 480 | 133 |
| 50 | S | C | 33 | 480 | 36 | 169 | 307 | 89 | 105 | 101 |
| 51 | S | B | 480 | 480 | 17 | 480 | 180 | 112 | 128 | 192 |
| 52 | F | B | 84 | 480 | 60 | 330 | 480 | 443 | 227 | 116 |
| 53 | S | A | 175 | 54 | 29 | 105 | 98 | 118 | 480 | 98 |
| 54 | F | A | 68 | 48 | 480 | 290 | 480 | 75 | 144 | 188 |

SAS CODE FOR RESPONSE TIME DATA ANALYSIS

```
DATA TIMES;
   INFILE TIMES;
   INPUT SUBJ SPEED $ ANIM $ PROB TIME RESP;
LABEL  SUBJ = ' SUBJECT '
     SPEED = ' SPEED OF ANIMATION '
     ANIM = ' TYPE OF ANIMATION '
     PROB = ' PROBLEM NUMBER '
     TIME = ' IDENTIFICATION TIME '
     RESP = ' RESPONSE TIME ';
PROC ANOVA;
   TITLE ' REPEATED MEASURES ANOVA FOR RESPONSE TIMES ';
   TITLE2 ' (PROBLEM IS THE REPEATED MEASURE) ';
   TITLE3 ' (SPEED & ANIMATION ARE CROSSED FACTORS)';
   TITLE4 ' (SUBJECTS ARE NESTED IN SPEED & ANIMATION)';
   CLASSES SUBJ SPEED ANIM PROB;
   MODEL RESP = SPEED  ANIM  SPEED*ANIM  SUBJ(SPEED ANIM)
           PROB  SPEED*PROB  ANIM*PROB
           SPEED*ANIM*PROB   PROB*SUBJ(SPEED ANIM);
   MEANS SPEED|ANIM / TUKEY E=SUBJ(SPEED ANIM);
   MEANS PROB SPEED*PROB ANIM*PROB SPEED*ANIM*PROB
         / TUKEY E=PROB*SUBJ(SPEED ANIM);
   TEST H=SPEED ANIM SPEED*ANIM  E=SUBJ(SPEED ANIM);
   TEST H=PROB SPEED*PROB ANIM*PROB SPEED*ANIM*PROB
                  E=PROB*SUBJ(SPEED ANIM);
PROC SORT DATA=TIMES;
   BY SPEED;
PROC ANOVA DATA=TIMES;
   BY SPEED;
   TITLE ' SIMPLE EFFECTS F TEST FOR SPEED*ANIMATION INTERACTION ';
   TITLE2 ' DATA IS SORTED BY SPEED ';
   CLASSES SUBJ ANIM PROB;
   MODEL RESP = ANIM SUBJ(ANIM) PROB ANIM*PROB PROB*SUBJ(ANIM);
     TEST H = ANIM E=SUBJ(ANIM);
     TEST H = PROB ANIM*PROB E=PROB*SUBJ(ANIM);
PROC SORT DATA=TIMES;
   BY PROB;
PROC ANOVA DATA=TIMES;
   BY PROB;
   TITLE ' SIMPLE EFFECTS F TEST FOR INTERACTIONS WITH PROBLEM ';
   TITLE2 ' DATA IS SORTED BY PROBLEM ';
   CLASSES SUBJ ANIM SPEED;
   MODEL RESP = ANIM SPEED SPEED*ANIM SUBJ(SPEED ANIM);
     TEST H = SPEED ANIM SPEED*ANIM E=SUBJ(SPEED ANIM);
     TEST H = SPEED ANIM SPEED*ANIM E=SUBJ(SPEED ANIM);
```

RANK.DAT NORMALIZED GEOMETRIC MEAN ANIMATION RATINGS

| SUBJ | SA | SB | SC | FA | FB | FC |
|---|---|---|---|---|---|---|
| 1 | .452 | .043 | .098 | .254 | .023 | .129 |
| 2 | .411 | .125 | .231 | .065 | .039 | .129 |
| 3 | .032 | .078 | .511 | .027 | .070 | .283 |
| 4 | .469 | .027 | .115 | .290 | .025 | .075 |
| 5 | .434 | .044 | .262 | .123 | .027 | .110 |
| 6 | .399 | .059 | .152 | .235 | .018 | .136 |
| 7 | .383 | .031 | .279 | .138 | .022 | .147 |
| 8 | .220 | .027 | .552 | .062 | .023 | .117 |
| 9 | .506 | .146 | .101 | .166 | .043 | .038 |
| 10 | .323 | .035 | .302 | .186 | .018 | .136 |
| 11 | .420 | .039 | .118 | .279 | .019 | .125 |
| 12 | .269 | .032 | .508 | .060 | .014 | .118 |
| 14 | .430 | .049 | .269 | .141 | .017 | .094 |
| 15 | .285 | .043 | .484 | .071 | .016 | .102 |
| 16 | .330 | .043 | .294 | .140 | .031 | .163 |
| 17 | .438 | .033 | .256 | .172 | .019 | .083 |
| 18 | .348 | .044 | .370 | .131 | .025 | .083 |
| 19 | .515 | .023 | .284 | .077 | .023 | .077 |
| 20 | .319 | .080 | .087 | .188 | .022 | .304 |
| 21 | .374 | .070 | .390 | .038 | .107 | .021 |
| 22 | .167 | .045 | .139 | .356 | .018 | .276 |
| 23 | .491 | .074 | .174 | .201 | .018 | .041 |
| 24 | .437 | .036 | .254 | .141 | .019 | .113 |
| 25 | .447 | .038 | .289 | .089 | .017 | .120 |
| 26 | .446 | .035 | .310 | .120 | .015 | .074 |
| 27 | .402 | .061 | .222 | .180 | .020 | .116 |
| 28 | .100 | .034 | .290 | .120 | .025 | .432 |
| 29 | .286 | .035 | .481 | .105 | .016 | .077 |
| 30 | .348 | .149 | .211 | .162 | .061 | .068 |
| 31 | .446 | .050 | .209 | .156 | .019 | .120 |
| 32 | .456 | .039 | .177 | .199 | .042 | .087 |
| 33 | .409 | .083 | .251 | .152 | .022 | .083 |
| 34 | .263 | .134 | .492 | .016 | .031 | .064 |
| 35 | .442 | .061 | .273 | .108 | .028 | .088 |
| 36 | .349 | .063 | .308 | .163 | .023 | .094 |
| 37 | .103 | .144 | .543 | .027 | .040 | .144 |
| 38 | .470 | .035 | .285 | .122 | .021 | .067 |

| SUBJ | SA | SB | SC | FA | FB | FC |
|---|---|---|---|---|---|---|
| 39 | .403 | .031 | .354 | .110 | .026 | .076 |
| 40 | .524 | .039 | .229 | .104 | .017 | .088 |
| 41 | .443 | .024 | .323 | .105 | .019 | .087 |
| 42 | .485 | .057 | .090 | .272 | .034 | .063 |
| 43 | .217 | .038 | .287 | .137 | .030 | .291 |
| 44 | .403 | .104 | .152 | .034 | .136 | .171 |
| 45 | .396 | .030 | .322 | .128 | .022 | .102 |
| 46 | .375 | .030 | .126 | .330 | .021 | .118 |
| 47 | .246 | .160 | .329 | .085 | .069 | .110 |
| 49 | .541 | .030 | .121 | .164 | .017 | .126 |
| 50 | .142 | .029 | .137 | .305 | .047 | .341 |
| 51 | .442 | .265 | .081 | .027 | .051 | .134 |
| 52 | .117 | .032 | .465 | .068 | .016 | .302 |
| 53 | .163 | .041 | .327 | .082 | .020 | .367 |
| 54 | .091 | .043 | .084 | .277 | .019 | .487 |

SAS CODE FOR TRANSFORMED GEOMETRIC MEAN RATINGS

```
DATA RANKS;
   INFILE RANKS;
   INPUT SUBJ SPEED $ ANIM $ RANK;
   LRANK = LOG(RANK);
LABEL  SUBJ = ' SUBJECT '
     SPEED = ' SPEED OF ANIMATION '
     ANIM = ' TYPE OF ANIMATION '
     RANK  = ' NORMALIZED GEOMETRIC MEAN '
     LRANK = ' LOG OF RANK ';
PROC GLM;
   TITLE ' SUBJECTIVE RANKINGS OF ANIMATED PRESENTATIONS ';
   CLASSES SUBJ SPEED ANIM;
   MODEL  LRANK = SUBJ|SPEED|ANIM;
   OUTPUT OUT=RNKDAT P=PRED R=RESID;
   TEST H = SPEED  E=SUBJ*SPEED;
   TEST H = ANIM   E=SUBJ*ANIM;
   TEST H = SPEED*ANIM  E=SUBJ*SPEED*ANIM;
   MEANS SPEED / TUKEY E=SUBJ*SPEED;
   MEANS ANIM  / TUKEY E=SUBJ*ANIM;
   MEANS SPEED*ANIM;
PROC SORT DATA=RANKS;
   BY ANIM SPEED;
PROC GLM DATA=RANKS;
   BY ANIM SPEED;
   TITLE ' SIMPLE EFFECTS F TEST DATA SORTED BY ANIMATION & SPEED ';
   CLASSES SUBJ ;
   MODEL  LRANK = SUBJ;
PROC PRINT DATA=RNKDAT;
PROC SORT DATA=RANKS;
   BY SPEED;
PROC GLM DATA=RANKS;
   BY SPEED;
   TITLE ' SIMPLE EFFECTS F TEST FOR COMPONENT VARIANCES BY SPEED ';
   CLASSES SUBJ ANIM;
   MODEL  LRANK = SUBJ|ANIM;
PROC SORT DATA=RANKS;
   BY ANIM;
PROC GLM DATA=RANKS;
   BY ANIM;
   CLASSES SUBJ SPEED;
   MODEL LRANK = SUBJ|SPEED;
```

# Appendix C. SLAM and FORTRAN Code

This appendix contains the SLAM network code for problem scenarios one through eight. FORTRAN subroutines used to write the ASCII animation commands for each problem scenario are included after the SLAM network code.

The first problem had each and every car delay at the its respective light. The light was represented by a GATE.

```
GEN,SWIDER,TRAFFIC FLOW,12/15/93,1,,NO,,NO;
LIMITS,4,3,100;
INTLC,XX(1)=25.5,XX(2)=22.5,XX(3)=3.,XX(4)=0,XX(5)=0,XX(6)=1000,XX(7)=0;
INTLC,XX(8)=0,XX(9)=0,XX(10)=0,XX(11)=0,XX(14)=0,XX(15)=0,XX(16)=0;
INTLC,XX(17)=0,XX(18)=0,XX(19)=0,XX(20)=0,XX(21)=0,XX(22)=2.;
;
;                    Problem 1
;             Single Lane Traffic Analysis
;            ( Moving Cars Pause at Green Light )
;
NETWORK;
;
    RESOURCE/STARTA1,1/STARTA2,2;
    GATES/LIGHTA1,CLOSE,3/LIGHTA2,CLOSE,4;
;
;  GENERATE ARRIVALS TO ROADWAY ICON / BARGRAPH DISPLAYs
;
    CREATE,RNORM(9.,4.5,1),1,1,,1;       ARRIVALS (EASTBOUND)
     ACT,,ATRIB(1).LE.XX(20),DIE1;   CONFLICTING ARRIVALS
     ACT;
       ASSIGN,XX(14)=TNOW-XX(20)+0.5;  INTERARRIVAL TIME
       ASSIGN,XX(20)=ATRIB(1)+0.5;  NEW ARRIVAL COMPARISON TIME
       EVENT,1;                  PLACE CAR ON "EA" PATH
       ACT,5.,,QEA1;               PATH TRAVEL TIME
;
    CREATE,RNORM(12.,6.,2),1,1,,1;    ARRIVALS ROADWAY A (WEST)
     ACT,,ATRIB(1).LE.XX(21),DIE2;   CONFLICTING ARRIVALS
     ACT;
       ASSIGN,XX(15)=TNOW-XX(21)+0.5;  INTERARRIVAL TIME
       ASSIGN,XX(21)=ATRIB(1)+0.5;  NEW ARRIVAL COMPARISON TIME
       EVENT,2;                  PLACE CAR ON "WA" PATH
       ACT,5.,,QWA2;               PATH TRAVEL TIME
;
;
QEA1  AWAIT(1),STARTA1/1,,1;         AWAIT STARTING PLACE
     ACT,2.0,TNOW.GT.ATRIB(1),QLA1;   CAR BEGAN STOPPED
     ACT;                       CAR BEGAN MOVING
QLA1  AWAIT(3),LIGHTA1/1;          AWAIT GREEN LIGHT
;
       ASSIGN,XX(17)=XX(16)-TNOW;   MINIMUM CAR SPACING
;                         1 SECOND BETWEEN CARS
       GOON,1;
;
     ACT,XX(17),TNOW.LT.XX(16),CE2;
```

```
     ACT;
;
CE2      ASSIGN,XX(16)=TNOW+1.0;     NEW COMPARISON TIME

      FREE,STARTA1/1;
;
      EVENT,3;             PLACE CAR ON "EA1" PATH
     ACT,5.;             TRAVEL TIME IN SINGLE LANE
      EVENT,4;             PLACE CAR ON "EA2" PATH
     ACT,4.;             TRAVEL TIME
     COLCT,INT(1),EA WAIT,,1;   COLLECT EA PATH WAIT STATS
      EVENT,5;             DESTROY EXITING CAR
DIE1    TERM;               TERMINATE CAR ENTITY
;
QWA2   AWAIT(2),STARTA2/1,,1;      AWAIT STARTING PLACE
     ACT,2.0,TNOW.GT.ATRIB(1),QLA2;    CAR  BEGAN STOPPED
     ACT;                      CAR BEGAN MOVING
QLA2   AWAIT(4),LIGHTA2/1;         AWAIT GREEN LIGHT
;
       ASSIGN,XX(19)=XX(18)-TNOW;   MINIMUM CAR SPACING
;                    1 SECOND BETWEEN CARS

       GOON,1;
;
     ACT,XX(19),TNOW.LT.XX(18),CW2;
     ACT;
;
CW2      ASSIGN,XX(18)=TNOW+1.0;     NEW COMPARISON TIME
;

      FREE,STARTA2/1;          NEXT CAR IS FIRST
;
      EVENT,6;             PLACE CAR ON "WA1" PATH
     ACT,5.;             TRAVEL TIME IN SINGLE LANE
      EVENT,7;             PLACE CAR ON "WA2" PATH
     ACT,4.;             TRAVEL TIME
     COLCT,INT(1),WA WAIT,,1;   COLLECT EA PATH WAIT STATS
      EVENT,8;             DESTROY EXITING CAR
DIE2    TERM;               TERMINATE CAR ENTITY
;
;
;   TRAFFIC LIGHTS
;
     CREATE,,,,1;
     ACT,XX(3),,;           ALL LIGHTS RED
LOOP    OPEN,LIGHTA1;             LIGHT A1 TURNS GREEN
     EVENT,9;               CHANGE LIGHT BAR TO GREEN
```

```
;
;
    ACT,XX(1);            GREEN TIME LIGHTS A1
    EVENT,10;               CHANGE LIGHT BAR TO YELLOW
    ACT,1.;                 TRANSITION PERIOD
    CLOSE,LIGHTA1;              NOW CARS STOP AT YELLOW LIGHT
;
    ACT,XX(22);           REMAINING YELLOW TIME LIGHT A1
    EVENT,11;               CHANGE LIGHT BAR TO RED
;
    ACT,XX(3);            ALL LIGHTS RED
    OPEN,LIGHTA2;               LIGHT A2 TURNS GREEN
    EVENT,12;               CHANGE LIGHT BAR TO GREEN
;
;
    ACT,XX(2);            GREEN TIME LIGHT A2
    EVENT,13;               CHANGE LIGHT BAR TO YELLOW
    ACT,1.;                 TRANSITION PERIOD
    CLOSE,LIGHTA2;              NOW CARS STOP AT YELLOW LIGHT

;
    ACT,XX(22);           REMAINING YELLOW TIME LIGHT A2
    EVENT,14;               CHANGE LIGHT BAR TO RED
;
    ACT,XX(3),,LOOP;        BEGIN NEW CYCLE
    END;
;
INIT,0,480;
FIN;
```

The second problem adjusted the event timing so that westbound cars spent half the time on each road segment that eastbound cars spent.

```
GEN,SWIDER,TRAFFIC FLOW,12/15/93,1,,NO,,NO;
LIMITS,4,3,100;
INTLC,XX(1)=25.5,XX(2)=22.5,XX(3)=3.,XX(4)=0,XX(5)=0,XX(6)=1000,XX(7)=0;
INTLC,XX(8)=0,XX(9)=0,XX(10)=0,XX(11)=0,XX(14)=0,XX(15)=0,XX(16)=0;
INTLC,XX(17)=0,XX(18)=0,XX(19)=0,XX(20)=0,XX(21)=0,XX(22)=2.;
;
;                          Problem  2
;                   Single Lane Traffic Analysis
;                 ( Westbound Cars are Twice as Fast )
;
;
NETWORK;
;
    RESOURCE/STARTA1,1/STARTA2,2;
    GATES/LIGHTA1,CLOSE,3/LIGHTA2,CLOSE,4;
;
;  GENERATE ARRIVALS TO ROADWAY ICON / BARGRAPH DISPLAYs
;
    CREATE,RNORM(9.,4.5,1),1,1,,1;        ARRIVALS (EASTBOUND)
     ACT,,ATRIB(1).LE.XX(20),DIE1;    CONFLICTING ARRIVALS
     ACT;
      ASSIGN,XX(14)=TNOW-XX(20)+0.5;  INTERARRIVAL TIME
      ASSIGN,XX(20)=ATRIB(1)+0.5;  NEW ARRIVAL COMPARISON TIME
      EVENT,1;                    PLACE CAR ON "EA" PATH
      ACT,5.,,QEA1;                  PATH TRAVEL TIME
;
    CREATE,RNORM(12.,6.,2),1,1,,1;     ARRIVALS ROADWAY A (WEST)
     ACT,,ATRIB(1).LE.XX(21),DIE2;    CONFLICTING ARRIVALS
     ACT;
      ASSIGN,XX(15)=TNOW-XX(21)+0.5;  INTERARRIVAL TIME
      ASSIGN,XX(21)=ATRIB(1)+0.5;  NEW ARRIVAL COMPARISON TIME
      EVENT,2;                    PLACE CAR ON "WA" PATH
      ACT,2.5,,QWA2;                 PATH TRAVEL TIME is Halved
;
;
QEA1   AWAIT(1),STARTA1/1;          AWAIT STARTING PLACE
QLA1   AWAIT(3),LIGHTA1/1,,1;       AWAIT GREEN LIGHT
     ACT,2.0,TNOW.GT.ATRIB(1)+5.,CE1;   CAR BEGAN STOPPED
     ACT;                         CAR BEGAN MOVING
;
CE1       ASSIGN,XX(17)=XX(16)-TNOW;   MINIMUM CAR SPACING
       GOON,1;                    1 SECOND BETWEEN CARS
;
     ACT,XX(17),TNOW.LT.XX(16),CE2;
```

```
     ACT;
;
CE2      ASSIGN,XX(16)=TNOW+1.0;     NEW COMPARISON TIME
      FREE,STARTA1/1;
;
      EVENT,3;             PLACE CAR ON "EA1" PATH
     ACT,5.;             TRAVEL TIME
      EVENT,4;             PLACE CAR ON "EA2" PATH
     ACT,4.;             TRAVEL TIME
     COLCT,INT(1),EA WAIT,,1;   COLLECT EA PATH WAIT STATS
      EVENT,5;             DESTROY EXITING CAR
DIE1   TERM;                TERMINATE CAR ENTITY
;
QWA2  AWAIT(2),STARTA2/1;        AWAIT STARTING PLACE
QLA2  AWAIT(4),LIGHTA2/1,,1;      AWAIT GREEN LIGHT
     ACT,2.0,TNOW.GT.ATRIB(1)+2.5,CW1;   CAR BEGAN STOPPED
      ACT;                        CAR BEGAN MOVING
;
CW1      ASSIGN,XX(19)=XX(18)-TNOW;   MINIMUM CAR SPACING
       GOON,1;                 1 SECOND BETWEEN CARS
;
     ACT,XX(19),TNOW.LT.XX(18),CW2;
     ACT;
;
CW2      ASSIGN,XX(18)=TNOW+1.0;     NEW COMPARISON TIME
      FREE,STARTA2/1;
;
      EVENT,6;             PLACE CAR ON "WA1" PATH
     ACT,2.5;             TRAVEL TIME is Halved
      EVENT,7;             PLACE CAR ON "WA2" PATH
     ACT,2.;             TRAVEL TIME  is Halved
     COLCT,INT(1),WA WAIT,,1;   COLLECT EA PATH WAIT STATS
      EVENT,8;            DESTROY EXITING CAR
DIE2   TERM;                TERMINATE CAR ENTITY
;
;
;  TRAFFIC LIGHTS
;
     CREATE,,,,1;
     ACT,XX(3),,;             ALL LIGHTS RED
LOOP   OPEN,LIGHTA1;              LIGHT A1 TURNS GREEN
     EVENT,9;                CHANGE LIGHT BAR TO GREEN
;
;
     ACT,XX(1);              GREEN TIME LIGHTS A1
     EVENT,10;                CHANGE LIGHT BAR TO YELLOW
     ACT,1.;                 TRANSITION PERIOD
```

```
     CLOSE,LIGHTA1;          NOW CARS STOP AT YELLOW LIGHT
;
     ACT,XX(22);           REMAINING YELLOW TIME LIGHT A1
     EVENT,11;              CHANGE LIGHT BAR TO RED
;
     ACT,XX(3);            ALL LIGHTS RED
     OPEN,LIGHTA2;           LIGHT A2 TURNS GREEN
     EVENT,12;              CHANGE LIGHT BAR TO GREEN
;
;
     ACT,XX(2);            GREEN TIME LIGHTS A2
     EVENT,13;              CHANGE LIGHT BAR TO YELLOW
     ACT,1.;                TRANSITION PERIOD
     CLOSE,LIGHTA2;          NOW CARS STOP AT YELLOW LIGHT
;
     ACT,XX(22);           REMAINING YELLOW TIME LIGHT A2
     EVENT,14;              CHANGE LIGHT BAR TO RED
;
     ACT,XX(3),,LOOP;       BEGIN NEW CYCLE
     END;
;
INIT,0,480;
FIN;
```

The third generated a conflicting arrival along with every other car by creating an entity that
entered the network only .25 seconds behind the original car arrival.

```
GEN,SWIDER,TRAFFIC FLOW,12/15/93,1,,NO,,NO;
LIMITS,4,3,100;
INTLC,XX(1)=26.,XX(2)=26.,XX(3)=3.,XX(4)=0,XX(5)=0,XX(6)=1000,XX(7)=0;
INTLC,XX(8)=0,XX(9)=0,XX(10)=0,XX(11)=0,XX(12)=1.,XX(13)=1.,XX(14)=0;
INTLC,XX(15)=0,XX(16)=0,XX(17)=0,XX(18)=0,XX(19)=0,XX(20)=0,XX(21)=0;
INTLC,XX(22)=2.;
;
;                    Problem 3
;            Single Lane Traffic Analysis
;        ( Encroachment of Cars - Interarrival Problem )
;
;
NETWORK;
;
    RESOURCE/STARTA1,1/STARTA2,2;
    GATES/LIGHTA1,CLOSE,3/LIGHTA2,CLOSE,4;
;
;  GENERATE ARRIVALS TO ROADWAY ICON / BARGRAPH DISPLAYs
;
    CREATE,RNORM(10.5,5.25,1),1,1,,1;      ARRIVALS (EASTBOUND)
     ACT,,ATRIB(1).LE.XX(20),DIE1;   CONFLICTING ARRIVALS
     ACT;
       ASSIGN,XX(14)=TNOW-XX(20)+0.75;  INTERARRIVAL TIME
       ASSIGN,XX(20)=ATRIB(1)+0.75,2; ARRIVAL COMPARISON TIME
       ACT,,,EV1;               ORIGINAL ARRIVAL
;
       ACT;
       GOON,1;
;          A CONFLICT OCCURS EVERY OTHER ARRIVAL
        ACT,0.25,XX(12).LE.0.5,CON1;   CONFLICTING ARRIVAL
;
        ACT,,,D1;           NO CONFLICT
D1        ASSIGN,XX(12)=0;     RESET FOR CONFLICT NEXT TIME
        ACT,,,DIE1;
;
CON1        ASSIGN,XX(12)=1;     RESET FOR NO CONFLICT NEXT TIME
        ASSIGN,XX(14)=.25;   SET VARIABLE FOR BAR DISPLAY
;
EV1      EVENT,1;               PLACE CAR ON "EA" PATH
       ACT,5.,,QEA1;            PATH TRAVEL TIME
;
    CREATE,RNORM(10.5,5.25,4),1,1,,1;   ARRIVALS ROADWAY A (WEST)
     ACT,,ATRIB(1).LE.XX(21),DIE2;   CONFLICTING ARRIVALS
```

```
        ACT;
          ASSIGN,XX(15)=TNOW-XX(21)+0.75;   INTERARRIVAL TIME
          ASSIGN,XX(21)=ATRIB(1)+0.75,2; ARRIVAL COMPARISON TIME
          ACT,,,EV2;                ORIGINAL ARRIVAL
;
          ACT;
          GOON,1;
;             A CONFLICT OCCURS EVERY OTHER ARRIVAL
            ACT,0.25,XX(13).LE.0.5,CON2;    CONFLICTING ARRIVAL
;
            ACT,,,D2;           NO CONFLICT
D2          ASSIGN,XX(13)=0;    RESET FOR CONFLICT NEXT TIME
            ACT,,,DIE2;
;
CON2        ASSIGN,XX(13)=1;    RESET FOR NO CONFLICT NEXT TIME
            ASSIGN,XX(15)=.25;  SET VARIABLE FOR BAR DISPLAY
;
EV2       EVENT,2;              PLACE CAR ON "WA" PATH
          ACT,5.,,QWA2;             PATH TRAVEL TIME
;
;
QEA1  AWAIT(1),STARTA1/1;       AWAIT STARTING PLACE
QLA1  AWAIT(3),LIGHTA1/1,,1;    AWAIT GREEN LIGHT
        ACT,2.0,TNOW.GT.ATRIB(1)+5.,CE1;   CAR BEGAN STOPPED
        ACT;                    CAR BEGAN MOVING
;
CE1       ASSIGN,XX(17)=XX(16)-TNOW;   MINIMUM CAR SPACING
          GOON,1;               1 SECOND BETWEEN CARS
;
        ACT,XX(17),TNOW.LT.XX(16),CE2;
        ACT;
;
CE2       ASSIGN,XX(16)=TNOW+1.0;    NEW COMPARISON TIME
          FREE,STARTA1/1;
;
          EVENT,3;              PLACE CAR ON "EA1" PATH
        ACT,5.;                 TRAVEL TIME ON ONE-LANE
          EVENT,4;              PLACE CAR ON "EA2" PATH
        ACT,4.;                 TRAVEL TIME
        COLCT,INT(1),EA WAIT,,1;  COLLECT EA PATH WAIT STATS
          EVENT,5;              DESTROY EXITING CAR
DIE1    TERM;                   TERMINATE CAR ENTITY
;
QWA2  AWAIT(2),STARTA2/1;       AWAIT STARTING PLACE
QLA2  AWAIT(4),LIGHTA2/1,,1;    AWAIT GREEN LIGHT
        ACT,2.0,TNOW.GT.ATRIB(1)+5.,CW1;   CAR BEGAN STOPPED
```

```
     ACT;                         CAR BEGAN MOVING
;
CW1      ASSIGN,XX(19)=XX(18)-TNOW;   MINIMUM CAR SPACING
       GOON,1;                    1 SECOND BETWEEN CARS
;
     ACT,XX(19),TNOW.LT.XX(18),CW2;
     ACT;
;
CW2      ASSIGN,XX(18)=TNOW+1.0;     NEW COMPARISON TIME
      FREE,STARTA2/1;
;
      EVENT,6;              PLACE CAR ON "WA1" PATH
     ACT,5.;               TRAVEL TIME ON ONE-LANE
      EVENT,7;              PLACE CAR ON "WA2" PATH
     ACT,4.;               TRAVEL TIME
     COLCT,INT(1),WA WAIT,,1;   COLLECT EA PATH WAIT STATS
      EVENT,8;              DESTROY EXITING CAR
DIE2   TERM;                 TERMINATE CAR ENTITY
;
;
;  TRAFFIC LIGHTS
;
     CREATE,,,,1;
     ACT,XX(3),,;                ALL LIGHTS RED
LOOP   OPEN,LIGHTA1;                 LIGHT A1 TURNS GREEN
     EVENT,9;                    CHANGE LIGHT BAR TO GREEN
;
;
     ACT,XX(1);                  GREEN TIME LIGHTS A1
     EVENT,10;                    CHANGE LIGHT BAR TO YELLOW
     ACT,1.;                      TRANSITION PERIOD
     CLOSE,LIGHTA1;                 NOW CARS STOP AT YELLOW LIGHT

;
     ACT,XX(22);                  REMAINING YELLOW TIME LIGHT A1
     EVENT,11;                     CHANGE LIGHT BAR TO RED
;
     ACT,XX(3);                  ALL LIGHTS RED
     OPEN,LIGHTA2;                  LIGHT A2 TURNS GREEN
     EVENT,12;                     CHANGE LIGHT BAR TO GREEN
;
;
     ACT,XX(2);                  GREEN TIME LIGHTS A2
     EVENT,13;                     CHANGE LIGHT BAR TO YELLOW
     ACT,1.;                       TRANSITION PERIOD
     CLOSE,LIGHTA2;                 NOW CARS STOP AT YELLOW LIGHT
;
```

```
     ACT,XX(22);              REMAINING YELLOW TIME LIGHT A2
     EVENT,14;                  CHANGE LIGHT BAR TO RED
;
     ACT,XX(3),,LOOP;          BEGIN NEW CYCLE
     END;
INIT,0,480;
FIN;
```

This problem required the light timing to be offset from the opening of each gate so that the first car moved on to the bridge 2 seconds before the light turned green.

```
GEN,SWIDE",TRAFFIC FLOW,12/15/93,1,,NO,,NO;
LIMITS,4,3,100;
INTLC,XX(1)=23.5,XX(2)=18.5,XX(3)=3.,XX(4)=0,XX(5)=0,XX(6)=1000,XX(7)=0;
INTLC,XX(8)=0,XX(9)=0,XX(10)=0,XX(11)=0,XX(14)=0,XX(15)=0,XX(16)=0;
INTLC,XX(17)=0,XX(18)=0,XX(19)=0,XX(20)=0,XX(21)=0,XX(22)=2.;
;
;                  Problem 4
;            Single Lane Traffic Analysis
;            ( First Car Jumps the Light )
;
;
;
NETWORK;
;
   RESOURCE/STARTA1,1/STARTA2,2;
   GATES/LIGHTA1,CLOSE,3/LIGHTA2,CLOSE,4;
;
; GENERATE ARRIVALS TO ROADWAY ICON / BARGRAPH DISPLAYs
;
   CREATE,RNORM(9.0,4.5,1),1,1,,1;      ARRIVALS (EASTBOUND)
    ACT,,ATRIB(1).LE.XX(20),DIE1;   CONFLICTING ARRIVALS
    ACT;
     ASSIGN,XX(14)=TNOW-XX(20)+0.5;  INTERARRIVAL TIME
     ASSIGN,XX(20)=ATRIB(1)+0.5; NEW ARRIVAL COMPARISON TIME
     EVENT,1;                PLACE CAR ON "EA" PATH
     ACT,5.,,QEA1;             PATH TRAVEL TIME
;
   CREATE,RNORM(12.0,6.0,2),1,1,,1;    ARRIVALS ROADWAY A (WEST)
    ACT,,ATRIB(1).LE.XX(21),DIE2;   CONFLICTING ARRIVALS
    ACT;
     ASSIGN,XX(15)=TNOW-XX(21)+0.5; INTERARRIVAL TIME
     ASSIGN,XX(21)=ATRIB(1)+0.5; NEW ARRIVAL COMPARISON TIME
     EVENT,2;                PLACE CAR ON "WA" PATH
     ACT,5.,,QWA2;             PATH TRAVEL TIME
;
;
QEA1  AWAIT(1),STARTA1/1;         AWAIT STARTING PLACE
QLA1  AWAIT(3),LIGHTA1/1,,1;      AWAIT GREEN LIGHT
    ACT,2.0,TNOW.GT.ATRIB(1)+5.,CE1;   CAR BEGAN STOPPED
    ACT;                      CAR BEGAN MOVING
;
CE1      ASSIGN,XX(17)=XX(16)-TNOW;   MINIMUM CAR SPACING
     GOON,1;                  1 SECOND BETWEEN CARS
;
    ACT,XX(17),TNOW.LT.XX(16),CE2;
```

```
     ACT;
;
CE2      ASSIGN,XX(16)=TNOW+1.0;     NEW COMPARISON TIME
      FREE,STARTA1/1;
;
      EVENT,3;            PLACE CAR ON "EA1" PATH
     ACT,5.;             TRAVEL TIME
      EVENT,4;            PLACE CAR ON "EA2" PATH
     ACT,4.;             TRAVEL TIME
     COLCT,INT(1),EA WAIT,,1;   COLLECT EA PATH WAIT STATS
      EVENT,5;            DESTROY EXITING CAR
DIE1   TERM;               TERMINATE CAR ENTITY
;
QWA2  AWAIT(2),STARTA2/1;       AWAIT STARTING PLACE
QLA2  AWAIT(4),LIGHTA2/1,,1;      AWAIT GREEN LIGHT
     ACT,2.0,TNOW.GT.ATRIB(1)+5.0,CW1;   CAR BEGAN STOPPED
      ACT;                     CAR BEGAN MOVING
;
CW1      ASSIGN,XX(19)=XX(18)-TNOW;   MINIMUM CAR SPACING
       GOON,1;               1 SECOND BETWEEN CARS
;
     ACT,XX(19),TNOW.LT.XX(18),CW2;
     ACT;
;
CW2      ASSIGN,XX(18)=TNOW+1.0;     NEW COMPARISON TIME
      FREE,STARTA2/1;
;
      EVENT,6;            PLACE CAR ON "WA1" PATH
     ACT,5.;             TRAVEL TIME
      EVENT,7,            PLACE CAR ON "WA2" PATH
     ACT,4.;             TRAVEL TIME
     COLCT,INT(1),WA WAIT,,1;   COLLECT EA PATH WAIT STATS
      EVENT,8;            DESTROY EXITING CAR
DIE2   TERM;               TERMINATE CAR ENTITY
;
;
;  TRAFFIC LIGHTS          ( First Car Anticipates Green Light )
;
     CREATE,,,,1;
     ACT,XX(3),,;           ALL LIGHTS RED
LOOP   OPEN,LIGHTA1;            LIGHT A1 TURNS GREEN
     ACT,4.;        **** ANTICIPATION PROBLEM DELAY ****
     EVENT,9;              CHANGE LIGHT BAR TO GREEN
;
;
     ACT,XX(1);            GREEN TIME LIGHT A1
     EVENT,10;              CHANGE LIGHT BAR TO YELLOW
```

```
      ACT,1.;                   TRANSITION PERIOD
      CLOSE,LIGHTA1;               NOW CARS STOP AT YELLOW LIGHT

;
      ACT,XX(22);              YELLOW TIME LIGHT A1
      EVENT,11;                  CHANGE LIGHT BAR TO RED
;
;
      ACT,XX(3);               ALL LIGHTS RED
      OPEN,LIGHTA2;               LIGHT A2 TURNS GREEN
      ACT,4.;          ****  ANTICIPATION PROBLEM DELAY  ****
      EVENT,12;                  CHANGE LIGHT BAR TO GREEN
;
;
      ACT,XX(2);               GREEN TIME LIGHTS A2
      EVENT,13;                  CHANGE LIGHT BAR TO YELLOW
      ACT,1.;                    TRANSITION PERIOD
      CLOSE,LIGHTA2;               NOW CARS STOP AT YELLOW LIGHT
;
      ACT,XX(22);               YELLOW TIME LIGHT A2
      EVENT,14;                  CHANGE LIGHT BAR TO RED
;
      ACT,XX(3),,LOOP;           BEGIN NEW CYCLE
      END;
;
INIT,0,480;
FIN;
```

This problem was created by replacing the arrival distribution with a constant for eastbound cars.

```
GEN,SWIDER,TRAFFIC FLOW,12/15/93,1,,NO,,NO;
LIMITS,4,3,100;
INTLC,XX(1)=26.1,XX(2)=21.9,XX(3)=3.,XX(4)=0,XX(5)=0,XX(6)=1000;
INTLC,XX(7)=0,XX(8)=0,XX(9)=0,XX(10)=0,XX(11)=0,XX(14)=0,XX(15)=0;
INTLC,XX(16)=0,XX(17)=0,XX(18)=0,XX(19)=0,XX(20)=0,XX(21)=0,XX(22)=2.;
;
;                  Problem 5
;           Single Lane Traffic Analysis
;        ( Eastbound Cars Arrive at Constant Rate )
;
;
NETWORK;
;
    RESOURCE/STARTA1,1/STARTA2,2;
    GATES/LIGHTA1,CLOSE,3/LIGHTA2,CLOSE,4;
;
; GENERATE ARRIVALS TO ROADWAY ICON / BARGRAPH DISPLAYs
;
    CREATE,7,1,1,,1;        ARRIVALS (EASTBOUND)
     ACT,,ATRIB(1).LE.XX(20),DIE1;    CONFLICTING ARRIVALS
     ACT;
       ASSIGN,XX(14)=TNOW-XX(20)+0.5;  INTERARRIVAL TIME
       ASSIGN,XX(20)=ATRIB(1)+0.5;  NEW ARRIVAL COMPARISON TIME
       EVENT,1;                PLACE CAR ON "EA" PATH
       ACT,5.,,QEA1;              PATH TRAVEL TIME
;
    CREATE,RNORM(9.,4.5,1),1,1,,1;    ARRIVALS ROADWAY A (WEST)
     ACT,,ATRIB(1).LE.XX(21),DIE2;    CONFLICTING ARRIVALS
     ACT;
       ASSIGN,XX(15)=TNOW-XX(21)+0.5;  INTERARRIVAL TIME
       ASSIGN,XX(21)=ATRIB(1)+0.5;  NEW ARRIVAL COMPARISON TIME
       EVENT,2;                PLACE CAR ON "WA" PATH
       ACT,5.,,QWA2;              PATH TRAVEL TIME
;
;
QEA1  AWAIT(1),STARTA1/1;          AWAIT STARTING PLACE
QLA1  AWAIT(3),LIGHTA1/1,,1;       AWAIT GREEN LIGHT
     ACT,2.0,TNOW.GT.ATRIB(1)+5.,CE1;    CAR BEGAN STOPPED
     ACT;                      CAR BEGAN MOVING
;
CE1      ASSIGN,XX(17)=XX(16)-TNOW;    MINIMUM CAR SPACING
       GOON,1;
;
     ACT,XX(17),TNOW.LT.XX(16),CE2;
```

```
     ACT;
;
CE2      ASSIGN,XX(16)=TNOW+1.0;     NEW COMPARISON TIME
      FREE,STARTA1/1;
;
      EVENT,3;            PLACE CAR ON "EA1" PATH
     ACT,5.;             TRAVEL TIME
      EVENT,4;            PLACE CAR ON "EA2" PATH
     ACT,4.;             TRAVEL TIME
     COLCT,INT(1),EA WAIT,,1;  COLLECT EA PATH WAIT STATS
      EVENT,5;            DESTROY EXITING CAR
DIE1  TERM;               TERMINATE CAR ENTITY
;
QWA2  AWAIT(2),STARTA2/1;       AWAIT STARTING PLACE
QLA2  AWAIT(4),LIGHTA2/1,,1;    AWAIT GREEN LIGHT
     ACT,2.0,TNOW.GT.ATRIB(1)+5.,CW1;  CAR BEGAN STOPPED
     ACT;                     CAR BEGAN MOVING
;
CW1      ASSIGN,XX(19)=XX(18)-TNOW;  MINIMUM CAR SPACING
       GOON,1;
;
     ACT,XX(19),TNOW.LT.XX(18),CW2;
     ACT;
;
CW2      ASSIGN,XX(18)=TNOW+1.0;     NEW COMPARISON TIME
      FREE,STARTA2/1;
;
      EVENT,6;            PLACE CAR ON "WA1" PATH
     ACT,5.;             TRAVEL TIME
      EVENT,7;            PLACE CAR ON "WA2" PATH
     ACT,4.;             TRAVEL TIME
     COLCT,INT(1),WA WAIT,,1;  COLLECT EA PATH WAIT STATS
      EVENT,8;           DESTROY EXITING CAR
DIE2  TERM;               TERMINATE CAR ENTITY
;
;
;  TRAFFIC LIGHTS
;
     CREATE,,,,1;
     ACT,XX(3),,;             ALL LIGHTS RED
LOOP  OPEN,LIGHTA1;                LIGHT A1 TURNS GREEN
     EVENT,9;                 CHANGE LIGHT BAR TO GREEN
;
;
     ACT,XX(1);               GREEN TIME LIGHT A1
     EVENT,10;                 CHANGE LIGHT BAR TO YELLOW
     ACT,1.;                   TRANSITION PERIOD
```

```
         CLOSE,LIGHTA1;              NOW CARS STOP AT YELLOW LIGHT
;
         ACT,XX(22);              YELLOW TIME LIGHT A1
         EVENT,11;                  CHANGE LIGHT BAR TO RED
;
         ACT,XX(3);               ALL LIGHTS RED
         OPEN,LIGHTA2;               LIGHT A2 TURNS GREEN
         EVENT,12;                  CHANGE LIGHT BAR TO GREEN
;
;
         ACT,XX(2);               GREEN TIME LIGHTS A2
         EVENT,13;                  CHANGE LIGHT BAR TO YELLOW
         ACT,1.;                    TRANSITION PERIOD
         CLOSE,LIGHTA2;              NOW CARS STOP AT YELLOW LIGHT
;
         ACT,XX(22);              YELLOW TIME LIGHT A2
         EVENT,14;                  CHANGE LIGHT BAR TO RED
;
         ACT,XX(3),,LOOP;           BEGIN NEW CYCLE
         END;
;
INIT,0,480;
FIN;
```

This problem was created by extending the event timing for eastbound cars on the last roadway segment so they would remain on the segment until they were terminated.

```
GEN,SWIDER,TRAFFIC FLOW,12/15/93,1,,NO,,NO;
LIMITS,4,3,100;
INTLC,XX(1)=27.5,XX(2)=20.5,XX(3)=3.,XX(4)=0,XX(5)=0,XX(6)=1000,XX(7)=0;
INTLC,XX(8)=0,XX(9)=0,XX(10)=0,XX(11)=0,XX(14)=0,XX(15)=0,XX(16)=0;
INTLC,XX(17)=0,XX(18)=0,XX(19)=0,XX(20)=0,XX(21)=0,XX(22)=2.;
;
;                    Problem 6
;              Single Lane Traffic Analysis
;           ( Eastbound Cars Terminate Slowly )
;
;
;
NETWORK;
;
    RESOURCE/STARTA1,1/STARTA2,2;
    GATES/LIGHTA1,CLOSE,3/LIGHTA2,CLOSE,4;
;
;  GENERATE ARRIVALS TO ROADWAY ICON / BARGRAPH DISPLAYs
;
    CREATE,RNORM(9.,4.5,7),1,1,,1;      ARRIVALS (EASTBOUND)
     ACT,,ATRIB(1).LE.XX(20),DIE1;   CONFLICTING ARRIVALS
     ACT;
       ASSIGN,XX(14)=TNOW-XX(20)+0.5;  INTERARRIVAL TIME
       ASSIGN,XX(20)=ATRIB(1)+0.5;  NEW ARRIVAL COMPARISON TIME
       EVENT,1;                PLACE CAR ON "EA" PATH
       ACT,5.,,QEA1;              PATH TRAVEL TIME
;
    CREATE,RNORM(12.,6.,8),1,1,,1;    ARRIVALS ROADWAY A (WEST)
     ACT,,ATRIB(1).LE.XX(21),DIE2;   CONFLICTING ARRIVALS
     ACT;
       ASSIGN,XX(15)=TNOW-XX(21)+0.5;  INTERARRIVAL TIME
       ASSIGN,XX(21)=ATRIB(1)+0.5;  NEW ARRIVAL COMPARISON TIME
       EVENT,2;                PLACE CAR ON "WA" PATH
       ACT,5.,,QWA2;              PATH TRAVEL TIME
;
;
QEA1   AWAIT(1),STARTA1/1;         AWAIT STARTING PLACE
QLA1   AWAIT(3),LIGHTA1/1,,1;      AWAIT GREEN LIGHT
     ACT,2.0,TNOW.GT.ATRIB(1)+5.,CE1;    CAR BEGAN STOPPED
     ACT;                      CAR BEGAN MOVING
;
CE1      ASSIGN,XX(17)=XX(16)-TNOW;   MINIMUM CAR SPACING
       GOON,1;                 1 SECOND BETWEEN CARS
;
     ACT,XX(17),TNOW.LT.XX(16),CE2;
```

```
      ACT;
;
CE2        ASSIGN,XX(16)=TNOW+1.0;      NEW COMPARISON TIME
       FREE,STARTA1/1;
;
       EVENT,3;            PLACE CAR ON "EA1" PATH
      ACT,5.;              TRAVEL TIME
       EVENT,4;            PLACE CAR ON "EA2" PATH
;
;                    BUILDUP OF CARS/BARS DUE TO
      ACT,19.;             EXTRA TRAVEL TIME ERROR
;
      COLCT,INT(1),EA WAIT,,1;   COLLECT EA PATH WAIT STATS
       EVENT,5;            DESTROY EXITING CAR
DIE1    TERM;              TERMINATE CAR ENTITY
;
QWA2  AWAIT(2),STARTA2/1;        AWAIT STARTING PLACE
QLA2  AWAIT(4),LIGHTA2/1,,1;     AWAIT GREEN LIGHT
      ACT,2.0,TNOW.GT.ATRIB(1)+5.0,CW1;   CAR BEGAN STOPPED
       ACT;                      CAR BEGAN MOVING
;
CW1       ASSIGN,XX(19)=XX(18)-TNOW;   MINIMUM CAR SPACING
        GOON,1;                  1 SECOND BETWEEN CARS
;
      ACT,XX(19),TNOW.LT.XX(18),CW2;
      ACT;
;
CW2       ASSIGN,XX(18)=TNOW+1.0;      NEW COMPARISON TIME
       FREE,STARTA2/1;
;
       EVENT,6;            PLACE CAR ON "WA1" PATH
      ACT,5.;              TRAVEL TIME
       EVENT,7;            PLACE CAR ON "WA2" PATH
      ACT,4.;              TRAVEL TIME  is Halved
      COLCT,INT(1),WA WAIT,,1;   COLLECT EA PATH WAIT STATS
       EVENT,8;            DESTROY EXITING CAR
DIE2    TERM;              TERMINATE CAR ENTITY
;
;
;  TRAFFIC LIGHTS
;
      CREATE,,,,1;
      ACT,XX(3),,;             ALL LIGHTS RED
LOOP    OPEN,LIGHTA1;              LIGHT A1 TURNS GREEN
      EVENT,9;                 CHANGE LIGHT BAR TO GREEN
;
;
```

```
      ACT,XX(1);              GREEN TIME LIGHT A1
      EVENT,10;                 CHANGE LIGHT BAR TO YELLOW
      ACT,1.;                   TRANSITION PERIOD
      CLOSE,LIGHTA1;              NOW CARS STOP AT YELLOW LIGHT
;
      ACT,XX(22);             REMAINING YELLOW TIME LIGHT A1
      EVENT,11;                 CHANGE LIGHT BAR TO RED
;
      ACT,XX(3);              ALL LIGHTS RED
      OPEN,LIGHTA2;               LIGHT A2 TURNS GREEN
      EVENT,12;                 CHANGE LIGHT BAR TO GREEN
;
;
      ACT,XX(2);              GREEN TIME LIGHT A2
      EVENT,13;                 CHANGE LIGHT BAR TO YELLOW
      ACT,1.;                   TRANSITION PERIOD
      CLOSE,LIGHTA2;              NOW CARS STOP AT YELLOW LIGHT
;
      ACT,XX(22);             REMAINING YELLOW TIME LIGHT A2
      EVENT,14;                 CHANGE LIGHT BAR TO RED
;
      ACT,XX(3),,LOOP;          BEGIN NEW CYCLE
      END;
;
INIT,0,480;
FIN;
```

This problem required timing of each light (GATE) which was inappropriate for the relative traffic (arrival distributions) in each direction.

```
GEN,SWIDER,TRAFFIC FLOW,12/15/93,1,,NO,,NO;
LIMITS,4,3,100;
INTLC,XX(1)=19.,XX(2)=19.,XX(3)=3.,XX(4)=0,XX(5)=0,XX(6)=1000;
INTLC,XX(7)=0,XX(8)=0,XX(9)=0,XX(10)=0,XX(11)=0,XX(14)=0,XX(15)=0;
INTLC,XX(16)=0,XX(17)=0,XX(18)=0,XX(19)=0,XX(20)=0,XX(21)=0,XX(22)=2.;
;
;                    Problem 7
;              Single Lane Traffic Analysis
;               ( Unbalanced Avg Queues)
;             ( Due to Improper Light Intervals )
;
NETWORK;
;
    RESOURCE/STARTA1,1/STARTA2,2;
    GATES/LIGHTA1,CLOSE,3/LIGHTA2,CLOSE,4;
;
;  GENERATE ARRIVALS TO ROADWAY ICON / BARGRAPH DISPLAYs
;
    CREATE,RNORM(10.2,5.1,3),1,1,,1;       ARRIVALS (EASTBOUND)
     ACT,,ATRIB(1).LE.XX(20),DIE1;   CONFLICTING ARRIVALS
     ACT;
       ASSIGN,XX(14)=TNOW-XX(20)+0.5;  INTERARRIVAL TIME
       ASSIGN,XX(20)=ATRIB(1)+0.5; NEW ARRIVAL COMPARISON TIME
       EVENT,1;                PLACE CAR ON "EA" PATH
       ACT,5.,,QEA1;             PATH TRAVEL TIME
;
    CREATE,RNORM(5.1,2.55,2),1,1,,1;    ARRIVALS ROADWAY A (WEST)
     ACT,,ATRIB(1).LE.XX(21),DIE2;   CONFLICTING ARRIVALS
     ACT;
       ASSIGN,XX(15)=TNOW-XX(21)+0.5;  INTERARRIVAL TIME
       ASSIGN,XX(21)=ATRIB(1)+0.5;  NEW ARRIVAL COMPARISON TIME
       EVENT,2;                PLACE CAR ON "WA" PATH
       ACT,5.,,QWA2;             PATH TRAVEL TIME
;
;
QEA1  AWAIT(1),STARTA1/1;        AWAIT STARTING PLACE
QLA1  AWAIT(3),LIGHTA1/1,,1;      AWAIT GREEN LIGHT
     ACT,2.0,TNOW.GT.ATRIB(1)+5.,CE1;   CAR BEGAN STOPPED
     ACT;                    CAR BEGAN MOVING
;
CE1      ASSIGN,XX(17)=XX(16)-TNOW;   MINIMUM CAR SPACING
       GOON,1;
;
     ACT,XX(17),TNOW.LT.XX(16),CE2;
```

```
     ACT;
;
CE2      ASSIGN,XX(16)=TNOW+1.0;     NEW COMPARISON TIME
      FREE,STARTA1/1;
;
      EVENT,3;              PLACE CAR ON "EA1" PATH
     ACT,5.;               TRAVEL TIME
      EVENT,4;              PLACE CAR ON "EA2" PATH
     ACT,4.;               TRAVEL TIME
     COLCT,INT(1),EA WAIT,,1;   COLLECT EA PATH WAIT STATS
      EVENT,5;              DESTROY EXITING CAR
DIE1   TERM;                 TERMINATE CAR ENTITY
;
QWA2  AWAIT(2),STARTA2/1;        AWAIT STARTING PLACE
QLA2  AWAIT(4),LIGHTA2/1,,1;      AWAIT GREEN LIGHT
     ACT,2.0,TNOW.GT.ATRIB(1)+5.,CW1;   CAR BEGAN STOPPED
     ACT;                      CAR BEGAN MOVING
;
CW1      ASSIGN,XX(19)=XX(18)-TNOW;   MINIMUM CAR SPACING
       GOON,1;
;
     ACT,XX(19),TNOW.LT.XX(18),CW2;
     ACT;
;
CW2      ASSIGN,XX(18)=TNOW+1.0;     NEW COMPARISON TIME
      FREE,STARTA2/1;
;
      EVENT,6;              PLACE CAR ON "WA1" PATH
     ACT,5.;               TRAVEL TIME
      EVENT,7;              PLACE CAR ON "WA2" PATH
     ACT,4.;               TRAVEL TIME
     COLCT,INT(1),WA WAIT,,1;   COLLECT EA PATH WAIT STATS
      EVENT,8;             DESTROY EXITING CAR
DIE2   TERM;                 TERMINATE CAR ENTITY
;
;
;  TRAFFIC LIGHTS
;
     CREATE,,,,1;
     ACT,XX(3),,;              ALL LIGHTS RED
LOOP   OPEN,LIGHTA1;              LIGHT A1 TURNS GREEN
     EVENT,9;                 CHANGE LIGHT BAR TO GREEN
;
;
     ACT,XX(1);               GREEN TIME LIGHT A1
     EVENT,10;                CHANGE LIGHT BAR TO YELLOW
     ACT,1.;                  TRANSITION PERIOD
```

```
     CLOSE,LIGHTA1;          NOW CARS STOP AT YELLOW LIGHT

;
     ACT,XX(22);          REMAINING YELLOW TIME LIGHT A1
     EVENT,11;              CHANGE LIGHT BAR TO RED
;
     ACT,XX(3);           ALL LIGHTS RED
     OPEN,LIGHTA2;            LIGHT A2 TURNS GREEN
     EVENT,12;              CHANGE LIGHT BAR TO GREEN
;
;
     ACT,XX(2);           GREEN TIME LIGHTS A2
     EVENT,13;              CHANGE LIGHT BAR TO YELLOW
     ACT,1.;                TRANSITION PERIOD
     CLOSE,LIGHTA2;           NOW CARS STOP AT YELLOW LIGHT
;
     ACT,XX(22);          REMAINING YELLOW TIME LIGHT A2
     EVENT,14;              CHANGE LIGHT BAR TO RED
;
     ACT,XX(3),,LOOP;       BEGIN NEW CYCLE
     END;
;
INIT,0,480;
FIN;
```

This problem was created by having too short of an interval (transition period) between lights. Insufficient time from one GATEs closing to the next GATEs opening allowed two-way traffic to exist on the bridge.

```
GEN,SWIDER,TRAFFIC FLOW,12/15/93,1,,NO,,NO;
LIMITS,4,3,100;
INTLC,XX(1)=27.5,XX(2)=24.5,XX(3)=1.,XX(4)=0,XX(5)=0,XX(6)=1000;
INTLC,XX(7)=0,XX(8)=0,XX(9)=0,XX(10)=0,XX(11)=0,XX(14)=0,XX(15)=0;
INTLC,XX(16)=0,XX(17)=0,XX(18)=0,XX(19)=0,XX(20)=0,XX(21)=0,XX(22)=2.;
;
;                  Problem  8
;           Single Lane Traffic Analysis
;           ( Two-Way Traffic Conflict )
;            ( on Single-Lane Bridge  )
;
NETWORK;
;
    RESOURCE/STARTA1,1/STARTA2,2;
    GATES/LIGHTA1,CLOSE,3/LIGHTA2,CLOSE,4;
;
;  GENERATE ARRIVALS TO ROADWAY ICON / BARGRAPH DISPLAYs
;
    CREATE,RNORM(4.5,2.25,2),1,1,,1;       ARRIVALS (EASTBOUND)
     ACT,,ATRIB(1).LE.XX(20),DIE1;   CONFLICTING ARRIVALS
     ACT;
      ASSIGN,XX(14)=TNOW-XX(20)+0.5;  INTERARRIVAL TIME
      ASSIGN,XX(20)=ATRIB(1)+0.5;  NEW ARRIVAL COMPARISON TIME
      EVENT,1;                PLACE CAR ON "EA" PATH
      ACT,8.,,QEA1;              PATH TRAVEL TIME
;
    CREATE,RNORM(5.1,2.55,1),1,1,,1;    ARRIVALS ROADWAY A (WEST)
     ACT,,ATRIB(1).LE.XX(21),DIE2;   CONFLICTING ARRIVALS
     ACT;
      ASSIGN,XX(15)=TNOW-XX(21)+0.5;  INTERARRIVAL TIME
      ASSIGN,XX(21)=ATRIB(1)+0.5;  NEW ARRIVAL COMPARISON TIME
      EVENT,2;                PLACE CAR ON "WA" PATH
      ACT,8.,,QWA2;              PATH TRAVEL TIME
;
;
QEA1  AWAIT(1),STARTA1/1;        AWAIT STARTING PLACE
QLA1  AWAIT(3),LIGHTA1/1,,1;     AWAIT GREEN LIGHT
     ACT,2.0,TNOW.GT.ATRIB(1)+8.,CE1;   CAR BEGAN STOPPED
     ACT;                    CAR BEGAN MOVING
;
CE1      ASSIGN,XX(17)=XX(16)-TNOW;   MINIMUM CAR SPACING
      GOON,1;
;
```

```
     ACT,XX(17),TNOW.LT.XX(16),CE2;
     ACT;
;
CE2       ASSIGN,XX(16)=TNOW+1.85;     NEW COMPARISON TIME
      FREE,STARTA1/1;
;
      EVENT,3;            PLACE CAR ON "EA1" PATH
     ACT,8.;             TRAVEL TIME
      EVENT,4;            PLACE CAR ON "EA2" PATH
     ACT,7.;             TRAVEL TIME
     COLCT,INT(1),EA WAIT,,1;  COLLECT EA PATH WAIT STATS
      EVENT,5;            DESTROY EXITING CAR
DIE1   TERM;               TERMINATE CAR ENTITY
;
QWA2  AWAIT(2),STARTA2/1;        AWAIT STARTING PLACE
QLA2  AWAIT(4),LIGHTA2/1,,1;     AWAIT GREEN LIGHT
     ACT,2.0,TNOW.GT.ATRIB(1)+8.,CW1;   CAR BEGAN STOPPED
     ACT;                     CAR BEGAN MOVING
;
CW1       ASSIGN,XX(19)=XX(18)-TNOW;   MINIMUM CAR SPACING
       GOON,1;
;
     ACT,XX(19),TNOW.LT.XX(18),CW2;
     ACT;
;
CW2       ASSIGN,XX(18)=TNOW+1.85;     NEW COMPARISON TIME
      FREE,STARTA2/1;
;
      EVENT,6;            PLACE CAR ON "WA1" PATH
     ACT,8.;             TRAVEL TIME
      EVENT,7;            PLACE CAR ON "WA2" PATH
     ACT,7.;             TRAVEL TIME
     COLCT,INT(1),WA WAIT,,1;  COLLECT EA PATH WAIT STATS
      EVENT,8;            DESTROY EXITING CAR
DIE2   TERM;               TERMINATE CAR ENTITY
;
;
;  TRAFFIC LIGHTS
;
     CREATE,,,,1;
     ACT,XX(3),,;          ALL LIGHTS RED
LOOP   OPEN,LIGHTA1;             LIGHT A1 TURNS GREEN
     EVENT,9;              CHANGE LIGHT BAR TO GREEN
;
;
     ACT,XX(1);            GREEN TIME LIGHT A1
     EVENT,10;              CHANGE LIGHT BAR TO YELLOW
```

```
    ACT,1.;              TRANSITION PERIOD
    CLOSE,LIGHTA1;          NOW CARS STOP AT YELLOW LIGHT
;
    ACT,XX(22);          REMAINING YELLOW TIME LIGHT A1
    EVENT,11;             CHANGE LIGHT BAR TO RED
;
    ACT,XX(3);           ALL LIGHTS RED
    OPEN,LIGHTA2;           LIGHT A2 TURNS GREEN
    EVENT,12;             CHANGE LIGHT BAR TO GREEN
;
;
    ACT,XX(2);           GREEN TIME LIGHT A2
    EVENT,13;             CHANGE LIGHT BAR TO YELLOW
    ACT,1.;               TRANSITION PERIOD
    CLOSE,LIGHTA2;          NOW CARS STOP AT YELLOW LIGHT
;
    ACT,XX(22);          YELLOW TIME LIGHT A2
    EVENT,14;             CHANGE LIGHT BAR TO RED
;
    ACT,XX(3),,LOOP;      BEGIN NEW CYCLE
    END;
;
INIT,0,480;
FIN;
```

C    SINGLE-LANE TRAFFIC ANALYSIS FORTRAN SUBROUTINES   13 DEC 93

```
      PROGRAM MAIN
      INCLUDE '/pgms/Slam/PARAM.INC'
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
*      COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW, II, MFA,
*     1MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(MEQT),
*     2SSL(MEQT),TNEXT, TNOW, XX(MMXXV)
      DIMENSION NSET(MNSET)
      COMMON QSET(MNSET)
      EQUIVALENCE (NSET(1),QSET(1))
      NNSET=MNSET
      NCRDR=5
      NPRNT=6
      NTAPE=7
      OPEN(UNIT=NCRDR,FILE='fort.5',STATUS='UNKNOWN')
      OPEN(UNIT=NPRNT,FILE='fort.6',STATUS='UNKNOWN')
*      write(10,*)'i got to main before slam call'
      CALL SLAM
      close(10)
      close(5)
      close(6)
      STOP
      END

      SUBROUTINE INTLC

      PARAMETER (MEQT=100, MSCND=25, MENTR=50, MRSC=75, MARR=50,
     1 MGAT=25, MHIST=50, MCELS=500, MCLCT=50, MSTAT=50,MEQV=100,
     2 MATRB=100, MFILS=100, MPLOT=10, MVARP=10, MSTRM=10,
     3 MACT=100, MNODE=500, MITYP=50, MMXXV=100, MNSET = 16000,
     4 MMXFLD=50)
      PARAMETER ( MAXLVL=50,MXMACS=20,MXBRKS=10)
      PARAMETER (MVARP1=MVARP+1)

      COMMON/SCOM1/ ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW, II, MFA,
     1MSTOP, NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(MEQT),
     2SSL(MEQT), TNEXT, TNOW, XX(MMXXV)

      OPEN(20,FILE='UNO.ATF',STATUS='UNKNOWN')   !ESTABLISH ATF FILE
      WRITE(20,*) 'TIME 0.00'
      WRITE(20,*) 'SET BAR EL COLOR RED'
      WRITE(20,*) 'SET BAR WL COLOR RED'
      RETURN
      END
```

```
      SUBROUTINE EVENT(I)

      PARAMETER (MEQT=100, MSCND=25, MENTR=50, MRSC=75, MARR=50,
     1 MGAT=25, MHIST=50, MCELS=500, MCLCT=50, MSTAT=50,MEQV=100,
     2 MATRB=100, MFILS=100, MPLOT=10, MVARP=10, MSTRM=10,
     3 MACT=100, MNODE=500, MITYP=50, MMXXV=100, MNSET = 16000,
     4 MMXFLD=50)
      PARAMETER ( MAXLVL=50,MXMACS=20,MXBRKS=10)
      PARAMETER (MVARP1=MVARP+1)

      COMMON/SCOM1/ ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW, II, MFA,
     1MSTOP, NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(MEQT),
     2SSL(MEQT), TNEXT, TNOW, XX(MMXXV)

      WRITE(20,5)TNOW          ! RECORD TIME OF CURRENT EVENT
5     FORMAT('TIME',F8.2)

      GO TO(10,20,25,30,35,40,45,50,60,65,70,75,80,85),I

      PRINT*, ' ATTENTION!! THERE IS AN ERROR IN EVENT ASSIGNMENTS '

10    CONTINUE                 ! EA CAR ARRIVAL
       XX(4) = XX(4) + 1       ! PROVIDE AN OBJECT NUMBER
       XX(5) = XX(5) + 1       ! INCR # OF EA CARS
       II = XX(5)
       ATRIB(3) = XX(4)        ! OBJECT NUMBER IS AN ATTRIBUTE
       WRITE(20,11)IFIX(ATRIB(3))  ! WRITE CREATE COMMAND
       WRITE(20,12)IFIX(ATRIB(3))  ! PLACE ON EASTBOUND PATH
       WRITE(20,13)II          ! SET BARGRAPH HT TO # CARS
       WRITE(20,14)XX(14)
11     FORMAT('CREATE EA ',I5,)
12     FORMAT('PLACE ',I5,' ON EA')
13     FORMAT('SET BAR LABAR ',I2,)
14     FORMAT('SET BAR EINT ',F8.1)
      RETURN

20     CONTINUE                ! WA CAR ARRIVAL
       XX(6) = XX(6) + 1       ! PROVIDE AN OBJECT NUMBER
       XX(7) = XX(7) + 1       ! INCR # OF WA CARS
       II = XX(7)
       ATRIB(3) = XX(6)        ! OBJECT NUMBER IS AN ATTRIBUTE
       WRITE(20,21)IFIX(ATRIB(3))  ! WRITE CREATE COMMAND
       WRITE(20,22)IFIX(ATRIB(3))  ! PLACE ON WA PATH
       WRITE(20,23)II          ! SET BARGRAPH HT TO # CARS
       WRITE(20,24)XX(15)
```

```
21    FORMAT('CREATE WA ',I5,)
22    FORMAT('PLACE ',I5,' ON WA')
23    FORMAT('SET BAR RABAR ',I2,)
24    FORMAT('SET BAR WINT ',F8.1)
   RETURN


25    CONTINUE                 ! CONTINUE FROM TRAFFIC LIGHT
      WRITE(20,27)IFIX(ATRIB(3))    ! PLACE ON EA1 PATH
27    FORMAT('PLACE ',I5,' ON EA1')
      XX(5) = XX(5) - 1         ! DECR # OF ENTERING CARS
      II = XX(5)
      WRITE(20,28)II            ! ADJUST BARGRAPH HT
28    FORMAT('SET BAR LABAR ',I2,)
       XX(8)=XX(8)+1            ! INCR # OF ONE-LANE CARS
       II=XX(8)
      WRITE(20,29)II            ! ADJUST ONE-LANE BAR GRAPH
29    FORMAT('SET BAR LEBAR ',I2)
   RETURN

30    CONTINUE                 ! CONTINUE FROM TRAFFIC LIGHT
      WRITE(20,31)IFIX(ATRIB(3))    ! PLACE ON EA2 PATH
31    FORMAT('PLACE ',I5,' ON EA2')
       XX(8)=XX(8)-1            ! DECR # OF ONE-LANE CARS
       II=XX(8)
      WRITE(20,32)II
32    FORMAT('SET BAR LEBAR ',I2)  ! ADJUST ONE-LANE BAR GRAPH
       XX(10)=XX(10)+1          ! INCR # OF EXITING CARS
       II=XX(10)
      WRITE(20,33)II
33    FORMAT('SET BAR LE ',I2)     ! ADJUST EXIT BAR GRAPH
   RETURN

35    CONTINUE                 ! EA CAR EXITS SYSTEM
      WRITE(20,37)IFIX(ATRIB(3))   ! DESTROY EA CAR
37    FORMAT('DESTROY ',I5,)
       XX(10)=XX(10)-1          ! DECR # OF EXITING CARS
       II=XX(10)
      WRITE(20,39)II            ! ADJUST EXIT BARGRAPH
39    FORMAT('SET BAR LE ',I2)
   RETURN

40    CONTINUE                 ! CONTINUE FROM TRAFFIC LIGHT
      WRITE(20,42)IFIX(ATRIB(3))    ! PLACE ON WA1 PATH
42    FORMAT('PLACE ',I5,' ON WA1')
      XX(7) = XX(7) - 1         ! DECR # OF ENTERING CARS
      II = XX(7)
```

```
      WRITE(20,43)II              ! ADJUST BARGRAPH HT
43     FORMAT('SET BAR RABAR ',I2,)
        XX(9)=XX(9)+1             ! INCR # OF ONE-LANE CARS
        II=XX(9)
      WRITE(20,44)II
44     FORMAT('SET BAR REBAR ',I2)    ! ADJUST MID BAR GRAPH
     RETURN

45    CONTINUE                   ! CONTINUE FROM TRAFFIC LIGHT
      WRITE(20,46)IFIX(ATRIB(3))    ! PLACE ON WA2 PATH
46     FORMAT('PLACE ',I5,' ON WA2')
      XX(9)=XX(9)-1               ! DECR # OF ONE-LANE CARS
      II=XX(9)
      WRITE(20,47)II
47     FORMAT('SET BAR REBAR ',I2)    ! ADJUST ONE-LANE BAR GRAPH
      XX(11)=XX(11)+1             ! INCR # OF EXITING CARS
      II=XX(11)
      WRITE(20,48)II
48     FORMAT('SET BAR RE ',I2)       ! ADJUST EXIT BAR GRAPH
     RETURN


50   CONTINUE                     ! WA CAR EXITS SYSTEM
      WRITE(20,52)IFIX(ATRIB(3))    ! DESTROY WA CAR
52     FORMAT('DESTROY ',I5,)
        XX(11)=XX(11)-1           ! DECR # OF EXITING CARS
        II=XX(11)
      WRITE(20,54)II
54     FORMAT('SET BAR RE ',I2)   ! ADJUST EXIT BAR GRAPH
     RETURN

60   CONTINUE
      WRITE(20,*) 'SET BAR EL COLOR GREEN'
     RETURN

65   CONTINUE
      WRITE(20,*) 'SET BAR EL COLOR YELLOW'
     RETURN

70   CONTINUE
      WRITE(20,*) 'SET BAR EL COLOR RED'
     RETURN

75   CONTINUE
      WRITE(20,*) 'SET BAR WL COLOR GREEN'
     RETURN
```

```
80  CONTINUE
     WRITE(20,*) 'SET BAR WL COLOR YELLOW'
    RETURN

85  CONTINUE
     WRITE(20,*) 'SET BAR WL COLOR RED'
    RETURN


     END


    SUBROUTINE OTPUT
    WRITE(20,1)            ! LABEL END OF ATF FILE
1    FORMAT('END')
    CLOSE(20)              ! CLOSE  ATF FILE
    RETURN
    END
```

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## Vita

Major Christopher L. Swider was born on 27 July 1959 in LaGrange, Illinois. He graduated from Proviso West High School in 1977 and attended the United States Air Force Academy, graduating with a Bachelor of Science in Electrical Engineering in May 1981. Upon graduation, he received a regular commission in the USAF and attended Undergraduate Pilot Training at Laughlin AFB, Texas. After graduating from pilot training, he served as a KC-135 co-pilot and aircraft commander at K.I. Sawyer AFB, Michigan. He completed Squadron Officer School in residence in 1986 and was assigned to the 4950th Test Wing at Wright-Patterson AFB, Ohio. In 1991,while assigned to the 4950th Test Wing, he completed a Master of Science degree in Engineering Management at the University of Dayton. Major Swider entered the School of Engineering, Air Force Institute of Technology, in August of 1992, pursuing the degree of Master of Science in Operations Research.

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This study examined two animation displays (moving icons, bar graphs) at two presentation speeds to determine how each of these factors affected the animation's ability to communicate violations of model assumptions. Subjects viewed animation displays individually and in combination at each presentation speed. Eight problem scenarios were presented to evaluate each animation's ability to communicate violations of different assumptions. Each animation's communication ability was measured subjectively and objectively. Subjective measures in the form of pairwise comparisons were used to calculate normalized preference ratings for each animation. Objective measures included problem identification accuracy and problem time. Subjective results indicated that moving icons and the slower presentation speed were the preferred factor levels. However, the combined display of bar graphs and moving icons was preferred most at the slower presentation speed. Objective results indicated that moving icons and the slower presentation speed were factor levels which significantly improved identification accuracy and response time for most problem scenarios. Although subjects preferred the combined display, they performed equally well with either of the two moving icon animations.

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